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Science&
Technology
REVIEW

Building Livermore's
Accelerator Capability

Also in this issue:
- Dose Assessment
- High Performance Storage Systems
- Detecting Clandestine Nuclear Tests

About the Cover

Lawrence Livermore employee Russell Pettit cuts portholes in one of the 26 high-power radio-frequency cavities being produced at the Laboratory for the B-Factory project under construction at the Stanford Linear Accelerator Center. Thick copper-plate bowls (also shown) are electron-beam welded to form the 200-kilogram cavities, which are then precision machined, electroplated, and finished on a diamond-turning machine in a 50-step process. The completed cavities are part of the system that will generate and maintain electron and positron beams at the proper energy level so that the B-Factory can carry on high-energy particle physics experiments. This research will provide important clues about what happened moments after the Big Bang to account for the preponderance of matter over antimatter in the universe. Our report on Livermore's multidisciplinary contributions to the B-Factory collaboration begins on p. 4.

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About the Review

Lawrence Livermore National Laboratory is operated by the University of California for the Department of Energy. At Livermore, we focus science and technology on assuring our nation's security. We also apply that expertise to solve other important national problems in energy, bioscience, and the environment. *Science & Technology Review* is published ten times a year to communicate, to a broad audience, the Laboratory's scientific and technological accomplishments in fulfilling its primary missions. The publication's goal is to help readers understand these accomplishments and appreciate their value to the individual citizen, the nation, and the world.

Please address any correspondence (including name and address changes) to *S&TR*, Mail Stop L-664, Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, California 94551, or telephone (510) 422-8961. Our electronic mail address is *hunter6@llnl.gov*.

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Joint Human Genome Institute operational

Lawrence Livermore has combined its human genome research efforts with those of Los Alamos National Laboratory and Lawrence Berkeley National Laboratory in the Department of Energy's new Joint Human Genome Institute, which begins operation in January.

Formation of the joint institute was announced in October by Martha Krebs, director of DOE's Office of Energy Research. Named scientific director of the institute was Elbert Branscomb, a senior scientist in Lawrence Livermore's Biology and Biotechnology Research Division.

With their resources combined, said Branscomb, the labs will work to advance knowledge of the basic structure of the entire human genome, or genetic blueprint, through a coordinated effort whose initial major emphasis will be high-throughput DNA sequencing.

For the past 10 years, researchers involved in the worldwide Human Genome Project have focused much of their efforts on mapping human DNA, as well as on developing the technology to do the sequencing. This work has progressed faster than expected, and researchers are now ready to undertake a full-scale assault on the sequencing task itself.

Besides contributing substantially to the worldwide sequencing effort, institute personnel are seeking to develop and apply new technologies for what Branscomb sees as the project's next great goal: deriving biological meaning from the otherwise cryptic sequence data.
Contact: Elbert Branscomb (510) 422-5681 (branscomb1@llnl.gov).

Lab chromosome work helps identify migraine gene

Using chromosome fragments obtained from Lawrence Livermore, medical researchers at Leiden University in the Netherlands have identified a gene that may hold a key to understanding and eventually treating migraine headache.

In the November 1, 1996, issue of the journal *Cell*, the Dutch researchers reported discovery of an abnormally structured gene in people suffering from a rare inherited form of migraine called familial hemiplegic migraine. They also found other alterations in the same gene in people with a similar neurological disorder called episodic ataxia type-2.

The gene regulates the transport of calcium into specific classes of brain cells. This movement of calcium regulates the release of neurotransmitters, which are critical elements in the network of communication among cells of the brain and nervous system. Scientists are hopeful that subsequent studies of the newly discovered gene could advance understanding of the cause of more common forms of migraine and be a step in developing possible treatments.

The gene resides on chromosome 19, the organization and structure of which have long been studied by the Laboratory's Human Genome Center. Three years ago, Dutch medical researchers contacted Livermore scientists for the physical map of the chromosome and for fragments of DNA from the region of chromosome 19 in which they were interested. The availability of these resources, a product of the Human Genome Project, were critical in facilitating the identification of the gene.

Authors of the *Cell* article included researchers from Leiden University, Lawrence Livermore, Stanford University, the London Health Science Centre in Canada, IRCC S. Raffaele in Italy, and Erasmus University in Rotterdam.
Contact: Harvey Mohrenweiser (510) 423-0534 (mohrenweiser1@llnl.gov).

Lab technology to help site oil wells

Laboratory scientists are helping oil producers more accurately determine the best places to site wells. The collaborative research project seeks to (1) develop better tiltmeters—instruments that measure changes in the tilt of the Earth's surface—and (2) improve computer models that predict tiltmeter signals. The result could be lower oil production costs and, ultimately, greater oil output.

Producing oil from American oil fields often requires "hydrofracturing"—the cracking of underground rock to provide channels through which oil can flow. Tiltmeters reveal the primary direction of cracking, which helps drillers decide where to sink additional wells. The Laboratory research project seeks to develop a tiltmeter that can work for hydrofractures as deep as 3 kilometers (10,000 feet). Currently, tiltmeter usefulness is limited to hydrofractures less than 1.8 kilometers (6,000 feet) deep; this is a significant limitation because 80% of all hydrofractures take place at depths greater than that.

To fine-tune computer models that predict tiltmeter signals from hydrofractures, researchers will combine data obtained from field tests of the new tiltmeters in California and Texas with existing geologic information supplied by oil companies. Accurate computer mapping of underground geology will help drillers decide where to place additional wells and how to hydrofracture them.

Dubbed the Tiltmeter Hydraulic Fracture Imaging Project, the venture is a collaboration between the Laboratory and Pinnacle Technologies Inc. of San Francisco. Additional contributors are the University of Texas at Austin, Sandia National Laboratories, and a number of oil companies.
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Accelerators at Livermore: Back to the Future

ACCELERATORS have played an important role in the history of Lawrence Livermore, and it is obvious that they will play an even more significant role in our future. Accelerator science currently constitutes a growing core competency for the Laboratory. One factor driving the growth of our accelerator capability is the fundamental relationship of accelerators to this Laboratory's national security mission.

Two major national security projects currently under way are using our accelerator expertise. The first is the Department of Energy's study of the Accelerator Production of Tritium (APT). In this facility, accelerator technology will be used to provide a new source for the tritium needed to maintain the safety and reliability of the nation's nuclear stockpile under the Stockpile Stewardship and Management Program. Los Alamos National Laboratory is leading a multilaboratory program to design the APT. At the request of the Department of Energy, we recently evaluated the Los Alamos technology incorporated in the preliminary design. We are now in partnership with Los Alamos and Brookhaven National Laboratory to make the APT a reality and will be making innovative—and cost-effective—engineering and physics contributions to final accelerator design.

Another critical national security project is the Advanced Hydrotest Facility. This planned facility will provide substantial improvements in dynamic radiography as a major tool for helping to make nuclear weapons safe and reliable without testing. The facility will be based on new accelerator technology, but it is not immediately obvious whether imaging with flash x rays produced from an electron beam or direct imaging with a proton beam is the better radiographic approach. One of Livermore's unique attributes is our capability not only to evaluate the relative advantages of photon versus proton imaging but also to determine the appropriate accelerator technology for each method.

The other factor driving the growth of our accelerator work is collaborations with other laboratories both in the U.S. and in Europe on large-scale physics research projects. One of our most important—and visible—accelerator collaborations is with the Stanford Linear Accelerator Center (SLAC) and Lawrence Berkeley National Laboratory (LBNL) to build the B-Factory at SLAC. The B-Factory project, described in an article beginning on , is one of the most exciting high-energy physics research efforts today. The facility will produce millions of subatomic particles called B mesons, thereby enabling physicists to determine why such a huge discrepancy now exists between the amounts of matter and antimatter in the universe.

The B-Factory is also important because we are demonstrating to the international science community that Lawrence Livermore is an ideal laboratory with which to collaborate in the area of accelerator science. Our B-Factory work has drawn international attention to Livermore's capabilities, in particular the way our physicists and engineers work together to solve problems in accelerator design, technology, and manufacturing. We have long been recognized for our accelerator engineering program. But our B-Factory effort has demonstrated what can happen when physicists work closely with engineers to creatively solve challenging accelerator problems. This world-class physics–engineering team, which is also making contributions to projects in Europe and elsewhere in the U.S., sets Lawrence Livermore apart from others in the nuclear and particle physics research world.

On the horizon is the Next Linear Collider, an exciting project that, like the B-Factory, will take us back to the very moment of the Big Bang. As described in the B-Factory article in this issue of *S&TR*, the extraordinary power of this new collider will require new accelerator designs and manufacturing methods. Wherever it is built, we are confident Livermore will be a key player in its design. We are working with LBNL and SLAC to tackle the biggest design challenges of the Next Linear Collider.

■ Richard Fortner is Associate Director of Physics and Space Technology.

The B-Factory and the Big Bang

Nearly 200 Livermore Laboratory specialists in accelerator technology and advanced manufacturing are helping to design and produce major components for the B-Factory at the Stanford Linear Accelerator Center, where experiments should reveal why so little antimatter is left over from the Big Bang.

ONE of the great mysteries of the universe is the overwhelming preponderance of matter over antimatter. Physicists believe that a few trillionths of a second after the universe was created—the so-called Big Bang— matter and antimatter existed in equal amounts. And yet, the known universe today is overwhelmingly made of matter, the result of some process long ago that must have favored matter over antimatter (see the box on p. 12).

Physicists believe the key to unraveling this mystery—and discovering the ancient origin of matter—is to follow closely the decay of a pair of artificially produced, extremely short-lived particles of matter and antimatter, the B meson and its antiparticle. A serious investigation, however, requires a "factory" designed to produce 30 million pairs of B mesons and anti-B mesons each year. Such a facility, a virtual "time machine" back to the earliest moments of the Big Bang, is now under construction at the Stanford Linear Accelerator Center (SLAC) near Menlo Park, California (see Figure 1).

Total project cost is $300 million, including the accelerator ($177 million), the detector ($73 million), and research and development costs. The B-Factory accelerator portion is a combined effort of SLAC, Lawrence Berkeley National Laboratory, and Lawrence Livermore National Laboratory.

The B-Factory's two underground rings, each 2,200 meters (a mile and a half) in circumference, will generate B mesons by colliding electrons and positrons (the antimatter counterpart of electrons) moving at near the speed of light. In helping to design and manufacture many of the major components and systems for the B-Factory rings and its giant, three-story-tall detector, Lawrence Livermore is strengthening its reputation as a world-class center of excellence for accelerator science and technology and high-energy physics. Nearly 200 Laboratory specialists representing a broad range of disciplines, from electroplating to particle physics, are contributing to the B-Factory effort.

The B-Factory work is only the latest chapter in a long history of Lawrence Livermore accelerator projects. Many have been built at Livermore, including the Advanced Test Accelerator, Flash X-Ray Facility, Experimental Test Accelerator, and LINAC, a 100-million-electron-volt linear accelerator. A team of Lawrence Livermore engineers and physicists contributed to designing parts
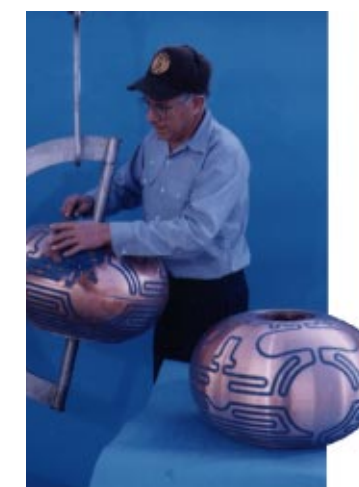
Figure 1. The B-Factory is under construction at the Stanford Linear Accelerator Center near Menlo Park, California. It consists of a portion of the existing 3.2-kilometer- (2-mile-) long linear accelerator, a new set of circular storage rings for electrons and positrons, and a large detector. (Photo courtesy of the Stanford Linear Accelerator Center.)
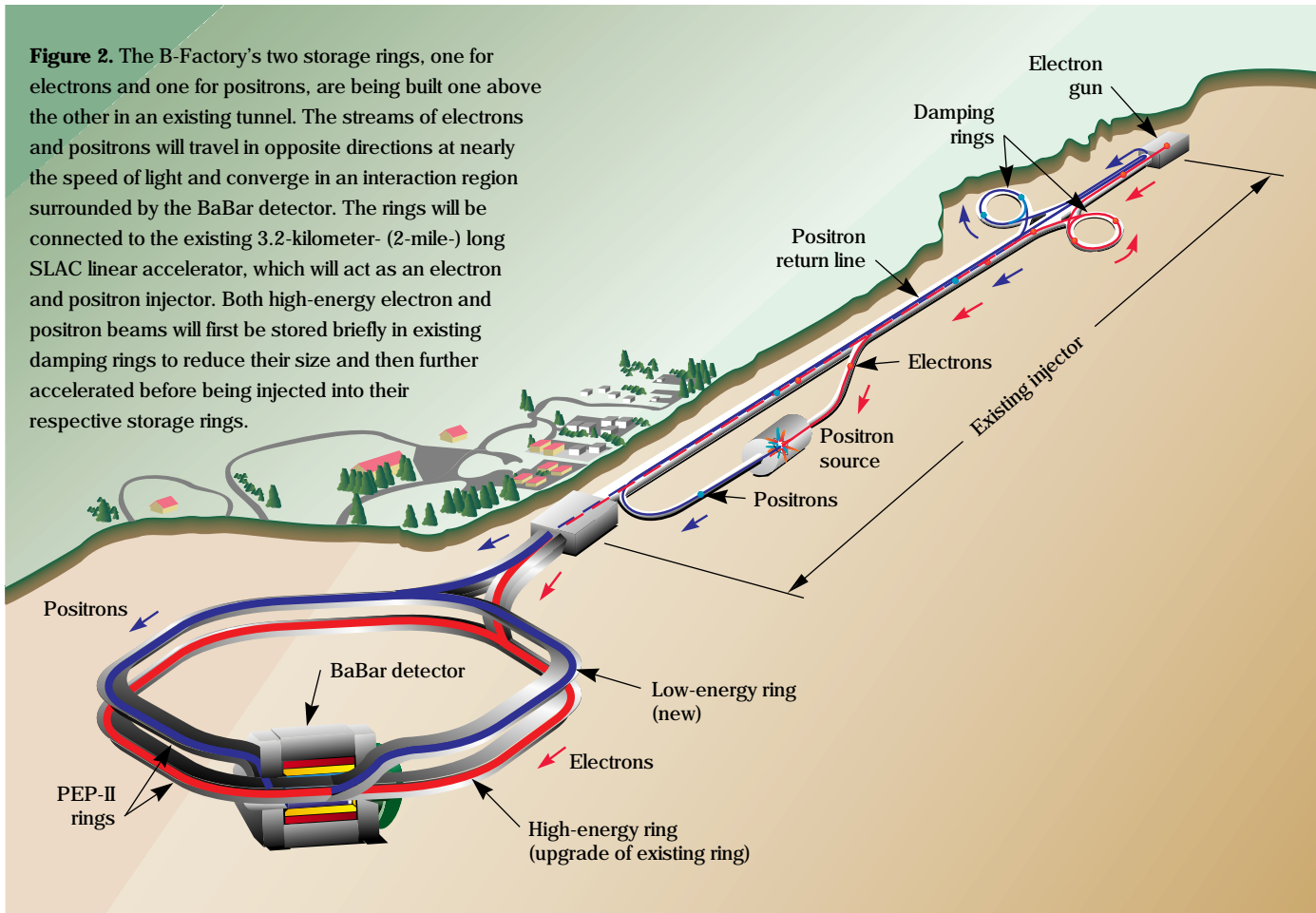
Figure 2. The B-Factory's two storage rings, one for electrons and one for positrons, are being built one above the other in an existing tunnel. The streams of electrons and positrons will travel in opposite directions at nearly the speed of light and converge in an interaction region surrounded by the BaBar detector. The rings will be connected to the existing 3.2-kilometer- (2-mile-) long SLAC linear accelerator, which will act as an electron and positron injector. Both high-energy electron and positron beams will first be stored briefly in existing damping rings to reduce their size and then further accelerated before being injected into their respective storage rings.

of the Department of Energy's Superconducting Super Collider before that enormous project was canceled. Accelerator work continues today in support of projects nationwide for the U.S. Department of Energy and overseas for Europe's nuclear research agency, CERN.

Accelerators also form a basic component of Lawrence Livermore programs. Examples include heavy-ion fusion research for inertial confinement fusion, the Center for Accelerator Mass Spectrometry for environmental research, and a host of accelerator-driven projects supporting the DOE's science-based Stockpile Stewardship and Management Program. Accelerator science is even impacting Lawrence Livermore health-care research efforts, where the Peregrine

computer simulation code adapts nuclear particle transport software to optimize radiation therapy for cancer patients.

Physicist Karl van Bibber, Livermore project leader for the B-Factory, suggests two key reasons for Lawrence Livermore's important contributions to past accelerator projects and its high potential for future successes. The first is the Laboratory's longstanding experience in managing large-scale, multidisciplinary, and multilaboratory projects. The second reason is the concentration of experts in such fields as computer simulation, lasers, advanced manufacturing, precision engineering, pulsed power, and materials science, who combine to form multidisciplinary teams producing innovative accelerator

component designs, engineering concepts, and manufacturing technologies.

Serving as a U.S. Flagship

Livermore accelerator expertise is most visible in its contributions to the B-Factory. Scheduled for completion in early 1999, the facility will be one of the flagships of the U.S. high-energy physics program, along with Fermi National Accelerator Laboratory's main ring injector upgrade to the Tevatron accelerator. Thousands of components, many of which will define the state of the art in accelerator technology, are being designed and built by the three partnering laboratories, which are working closely with a host of small and large U.S. contractors.

The B-Factory accelerator will consist of two storage rings built one above the other in an existing tunnel at the east end of SLAC (see Figure 2). The upper ring is for positrons; the lower for electrons (Figure 3). The rings will be connected to the existing 3.2-kilometer- (2-mile-) long SLAC linear accelerator, which will act as a particle injector. The positrons will be generated part way along the linear accelerator by crashing high-energy electrons into a cooled rotating tungsten target. Both the electrons and positrons are stored in existing damping rings, which will shrink the size of the beams, before they are reinjected and accelerated down to the storage rings. The streams of electrons and positrons travel in opposite directions at nearly the speed of light within 10-centimeter- (4-inch-) diameter metal beam pipes. Magnets guide these streams and narrow them to beams that are 1 to 2 millimeters wide. By the time the beams collide in the middle of the detector, they are flat "ribbons," about 6 micrometers high and 150 micrometers wide.

The construction project is making use of much of SLAC's existing PEP (Positron–Electron Project) facility. Work involves renovating the existing

high-energy PEP storage ring for the electrons, adding a new low-energy storage ring for the positrons, and installing a huge detector called BaBar* that encompasses the central part of the interaction region where the electrons and positrons are made to collide.

A key feature of this collider is that electrons and positrons will circulate and collide with unequal (or asymmetric) energies so scientists can better study the particles generated in the collisions. The electrons will be accelerated to 9 billion electron volts and the positrons to 3.1 billion electron volts. The asymmetric energy of the colliding electrons and positrons will create B mesons and anti-B mesons with a "kick" forward, away from the collision point, making it easier for the massive detector to pinpoint the origin of the B particles' decay products.

The project is expected to generate enormous amounts of raw data each year. The data will be distributed within a collaboration that includes nearly 500 physicists representing 75 institutions in the U.S., Canada, the United Kingdom, France, Italy, Germany, Russia, China, and Taiwan. Lawrence Livermore physicists will be part of the American team analyzing the long-awaited data.

Tri-Lab Planning

Planning began in 1990 when the directors of SLAC and Lawrence Berkeley and Lawrence Livermore laboratories agreed to a coordinated research and development effort aimed at completing a conceptual design report for a B-Factory sited at SLAC. On October 4, 1993, President Clinton announced the DOE decision in favor of the SLAC–LBNL–LLNL proposal over a competing one from Cornell University.

Although SLAC is the lead laboratory, project management is drawn from the three centers. "It's hard to tell that there are three labs— it's more like one superlab," says van Bibber. The three-lab partnership is flexible, allowing it to draw upon a broad base of expertise and thereby trade or share tasks among the laboratories. Indeed, the DOE has hailed the flexibility of the project's collective management and procurement activities as a model for major science projects throughout the department.

As an example, SLAC was initially responsible for fabricating a prototype of the high-power radio-frequency
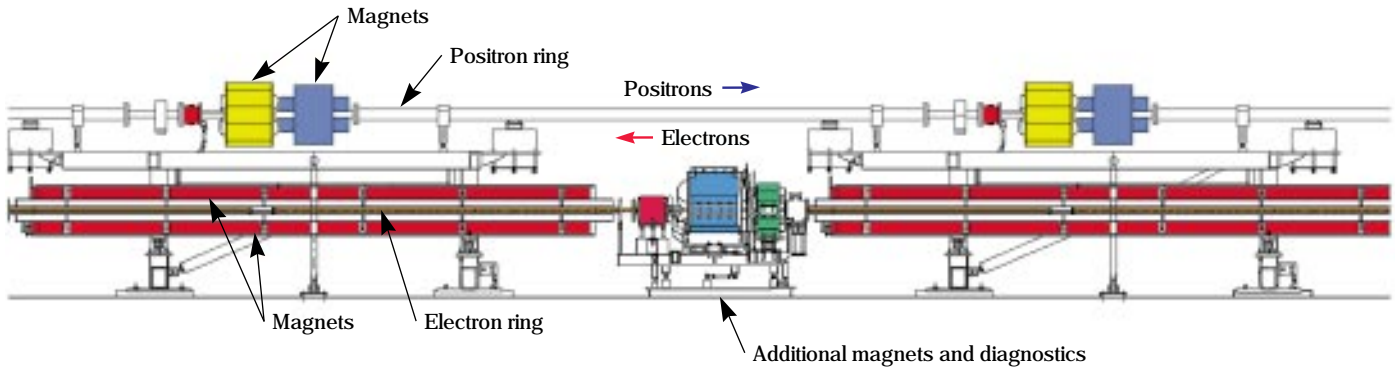
Figure 3. The B-Factory's two storage rings will be vertically stacked within the existing Positron–Electron Project (PEP) tunnel. The top ring, which is being added, is designed for positrons that will be continually guided and focused by a series of magnets. The bottom ring, designed for the more energetic electrons, requires more massive magnet systems encompassing the ring to keep the electron beams focused and on track. In the bottom center of the drawing is a complex of additional magnets and diagnostic equipment.

* The BaBar detector is named after the elephant in Jean de Brunhoff's children's stories and is a playful pun on the physics notation for B and anti-B mesons—B, $\overline{B}$—which is pronounced "B, B bar."

cavities, which will be attached in groups of two or four to 1-megawatt microwave generators to maintain the B-Factory's electron and positron beams at their proper energy levels in the high- and

Figure 4. Twenty-six high-power radio-frequency cavities in groups of two and four will be attached to 1-megawatt microwave generators to maintain the electron and positron beams at their proper energy leve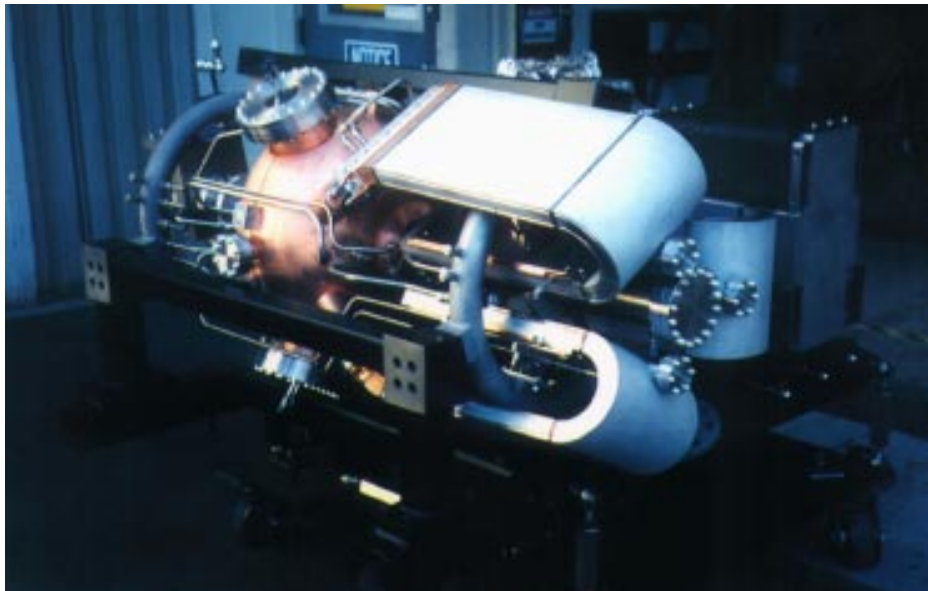ls in the high- and low-energy rings. One of the spherical cavities, machined at Livermore, is shown here at the Stanford Linear Accelerator Center, where it has been attached to a host of other parts.

low-energy rings (see Figure 4). Asked to lend a hand, Lawrence Livermore assembled a multidisciplinary team, led by Manufacturing and Materials Engineering Division specialists in numerically controlled milling, precision machining, electron-beam welding, and electrodeposition. After helping with the prototype, Livermore was given responsibility to build the first 8 cavities and then all 26.

Livermore's Contributions

The cavities, which have an interior diameter of 50 centimeters (20 inches), were designed as the most powerful of their kind ever built. They posed exceptionally challenging manufacturing problems for Livermore engineers and technicians. For example, because the cavity wall must dissipate over 100,000 watts of microwave power, an innovative manufacturing process was

developed to embed water channels in the cavity's outer surface to remove heat. First, the cavities' bowl shapes are pressed out of copper plate and then welded together using an electron beam. The channels are cut into the outside of the cavities, filled with wax, and plated with copper. The wax is melted and removed and the cavities precisely fitted with ports and flanges. (See Figure 5 for a summary of the cavity manufacturing process.)

Most of the machining is contracted to U.S. industry, with some extremely specialized fabrication and assembly activities centered at Lawrence Livermore. For example, the Laboratory's plating shop is one of the few places in the world capable of precisely electrodepositing a 1-centimeter (three-eighths-inch) layer of oxygen-free copper on the 200-kilogram (450-pound) cavities, a process that takes four weeks to complete (see May 1996 *S&TR*, pp. 28–30). All told, each cavity requires 50 different manufacturing steps and some 1,700 worker-hours to manufacture.

"Rarely in the history of the Laboratory have we faced so complex a manufacturing task as the cavities," notes Jeff Williams, head of Manufacturing and Materials Engineering Division. Williams says the task is made particularly challenging by the number of units (most of the time, the division makes one-of-a-kind items), the number of steps involved, and the number of different shops within the division that have gotten involved.

Given the original presumption that the cavities would be sole-sourced to a foreign vendor, American industry has greatly benefited from the relationship, both in new sales and new skills. "The Laboratory is acting as a master contractor. We're very proud that we're able to keep all of the work in the U.S.," says physicist Marshall Mugge, deputy project leader of the Laboratory's B-Factory activities.

Livermore experts are also cleaning nearly a kilometer of 2.4-meter- (8-foot-) long straight sections of beam pipes through a process called glow-discharge cleaning that rids the metal of residual carbon and contaminants. The process, conducted in Livermore clean rooms, is essential because an electron beam tends to attract dust particles left in the pipes much as static electricity does (see Figure 6). "Having extremely clean pipes will help ensure that the accelerator

starts out with a very good vacuum," says Mugge.

Another Livermore responsibility is a critical 5-meter- (16.4-foot-) long device called the distributed ion pump. The pump will be installed within each of the 192 dipole magnets around the high-energy ring. As the particle beams circle around, they will generate a huge amount of x-ray energy, which will heat the metal pipes. The pipes in turn will discharge hot gases, which must

be immediately removed to maintain the high vacuum conditions of 10^{-9} torr, or one-trillionth the atmospheric pressure of Earth at sea level.

Electrons streaming off the distributed ion pump will ionize the discharged gas, which will become quickly trapped inside the pump's cathode. Without such an effective pump, the beam would quickly attenuate by colliding with the contaminating gases. Because of the importance of
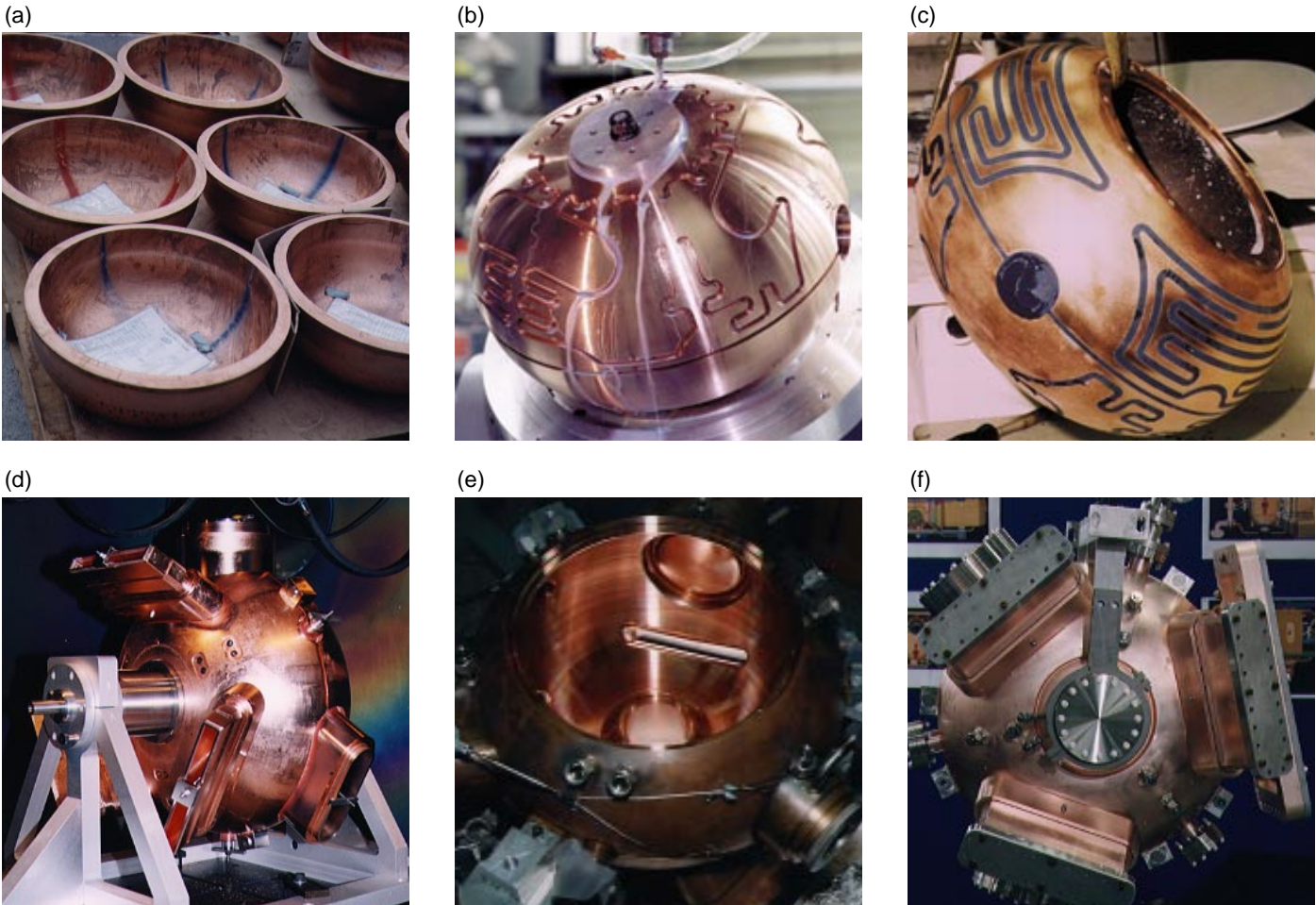
Figure 5. Six of the many steps in the radio-frequency cavity manufacturing process. (a) The radio-frequency cavities are formed from 2.54-centimeter- (1-Inch-) thick copper plates. (b) The machined bowls are electron-beam welded to form a cavity; then water channels are cut into the outer contour. (c) Wax is placed into the water channels before the cavity is plated with ultrapure copper approximately 1 centimeter (three-eighths inch) thick. (d) Several ports are attached to each cavity by electron-beam welding. (e) The cavity's surface is finished using a Livermore diamond-turning machine. (f) The final product is cleaned for ultrahigh-vacuum use and made ready for shipment to the Stanford Linear Accelerator Center for integration with other components.

Figure 6. Livermore engineers clean nearly a kilometer of 2.4-meter- (8-foot-) long straight sections of beam pipes through a process called glow-discharge cleaning that rids the metal of residual carbon and contaminants. Here, Fred Holdener works with a vacuum pump prior to cleaning operations.

maintaining a very high vacuum, successfully demonstrating the distributed ion pump was an important factor in showing that SLAC's B-Factory design was workable.
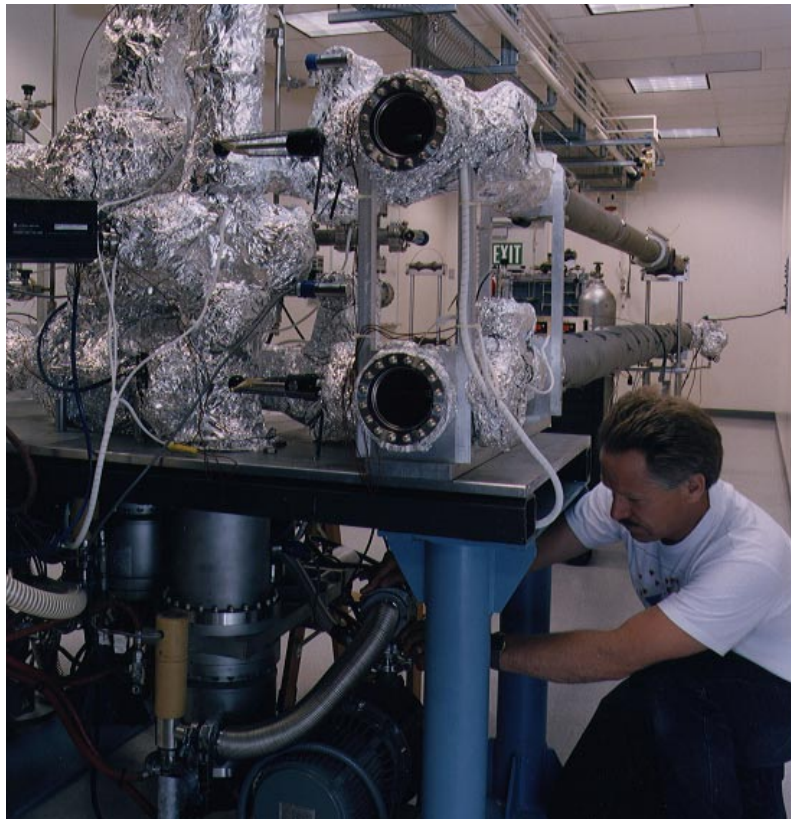
The pump is one of several key designs produced by the 60 engineers, designers, and technicians comprising Livermore's Accelerator Technologies Engineering Group, a part of the Mechanical Engineering Department's Applied Research Engineering Division. For supervisor Lou Bertolini, the group's success is due in part to working closely with physicists in the Physics and Space Technology Directorate. Another contributing factor is the broad range of group members' backgrounds that encourages taking innovative approaches to accelerator component design.

Where Beams Collide

Among LLNL's other major responsibilities is designing and

building the vacuum system and several critical diagnostic systems for the interaction region, a football-field-long assembly of magnets that guide and focus the opposing beams into the center of the giant BaBar detector (see Figure 7), where the collision occurs. Here, stability and alignment of the beam are crucial to the success of the project. For example, vacuum pressures must be extremely low—10^{-10} torr.

Without such extreme vacuum conditions, the beams would lose energy by colliding with residual air molecules. The vacuum is also necessary to reduce "noise" in the detector from interactions with gas molecules that would be confused with the large number of particles produced by B-particle decay.

"There are a tremendous number of components that have to come together at the same time in the interaction region. It's like assembling a one-of-a-kind exotic automobile," says Robert Yamamoto, deputy division leader of Applied Research Engineering Division and the coordinator for LLNL engineering work for the B-Factory.

The design of detector subsystems within BaBar has required close working relationships with research groups and manufacturers in Italy, Britain, China, and Russia. For example, the cesium iodide calorimeter, co-designed by Livermore physicists and engineers, is made of 6,000 cesium iodide crystals being manufactured in China and Russia. The 30-centimeter- (12-inch-) long crystals will measure various products from B-particle decay.

Another subsystem, the instrumented flux return (IFR), is a joint project of researchers at Livermore and in Italy. The IFR consists of a large number of specialized detectors called resistive plate chambers (RPCs). These chambers allow measurements of charged muons that traverse the outermost iron plates forming the magnetic field flux return for the BaBar detector. They also allow

the detection of certain decay products that can be used to enhance the data sample from the detector. Livermore physicists have built a special receiving and assembly area at SLAC and are now beginning to receive the first RPCs from Italian manufacturers for testing and commissioning.

Lawrence Livermore computational physicists are simulating events in the interaction region that are telling the international B-Factory research community how the detectors will track the tens of thousands of daily collisions between electrons and positrons. Livermore physicist Craig Wuest notes that the simulations are becoming increasingly realistic as detector designs are finalized and the systems manufactured and installed.

Beyond the B-Factory

The Laboratory's Accelerator Technologies Engineering Group is no stranger to large-scale accelerator projects, having done important work for the past several years for both U.S. and European experiments. Today, besides its B-Factory contributions, the group is designing and fabricating the magnet system for the Photon– Electron New Heavy Ion Experiment

(PHENIX) led by Brookhaven National Laboratory. The 3,500-ton magnet system measures 10 meters high, 10 meters across, and 20 meters long (30 by 30 by 60 feet). The group is also coordinating production by Russian mills of the massive amounts of iron needed for the project. The goal of PHENIX is to look for evidence of a primordial state of matter that last existed a few microseconds after the Big Bang.

The LLNL team is likewise supporting the Main Injector Neutrino Oscillation Search (MINOS), an experiment led by Fermi National Accelerator Laboratory that will search for muon neutrinos oscillating into electron neutrinos or tau neutrinos. Livermore activities focus on engineering several components, including a detector composed of 600 octagonal plates of 8-meter- (25-foot-) tall steel. Livermore physicists are also leading the research and development of resistive-plate-chamber technology for the 32,000 square meters (8 acres)

of active detectors that will be interleaved with the steel.

Enhancing Reputations

Van Bibber says Livermore's extensive B-Factory work, combined with support for other projects worldwide, augurs well for major Livermore participation in future accelerator projects. He also notes that many capabilities that are being brought to bear on the technical challenges of the B-Factory are supporting Lawrence Livermore's diverse efforts for the DOE Stockpile Stewardship Program.

"Our people have their feet in physics research as well as other applications," says van Bibber. "The solution we come up with for a B-Factory problem may also be used to solve new problems in defense sciences and vice versa."

For example, DOE's Accelerated Strategic Computing Initiative, which is being developed primarily for the
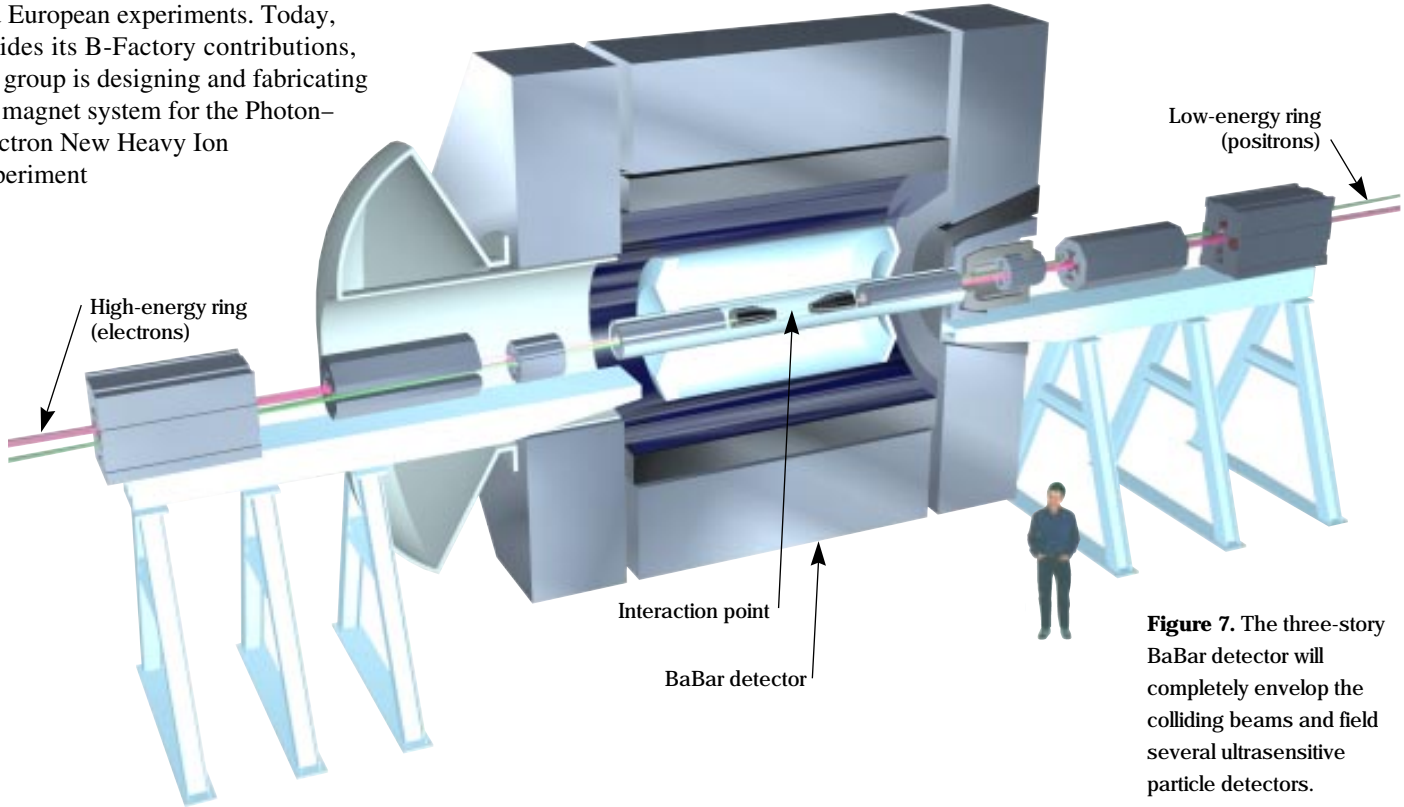

High-energy ring (electrons)

Low-energy ring (positrons)

Interaction point

BaBar detector

Figure 7. The three-story BaBar detector will completely envelop the colliding beams and field several ultrasensitive particle detectors.

Stockpile Stewardship Program, has direct applications to computer modeling of high-energy particle interactions. The Laboratory is also building upon its successful design of the B-Factory's distributed ion pump to design and develop the vacuum system for the Accelerator Production of Tritium facility planned at DOE's Savannah River operations. Livermore is collaborating with Los Alamos and Brookhaven on this option for cost-effectively producing tritium for the nation's nuclear stockpile.

Together with colleagues from Los Alamos, Livermore experts are also designing a new kind of camera that will use high-energy protons to penetrate thick, imploding objects and thereby reveal much more internal detail than do conventional flash x-ray machines. The proton radiography concept is under study for the DOE's Advanced Hydrotest Facility.

A Bright Future for the NLC

Laboratory physicists estimate that between now and 2010, the total budget for large accelerators in the world will total about $10 billion. The biggest American project on the drawing board is called the Next Linear Collider (NLC). The NLC is proposed as a 30-kilometer- (18.6-mile-) long facility to collide electrons and positrons at energies up to a trillion electron volts. Designed to probe more deeply the fundamental nature of the universe, the NLC requires a large luminosity necessitating that the beam width be no more than 40 atomic diameters to achieve the required data rate.

SLAC, Lawrence Berkeley, and Lawrence Livermore have signed a memorandum of understanding to collaborate on research and development for the NLC, which is expected to be built on or near an existing national laboratory by the consortium. The key to making the NLC a reality, van Bibber emphasizes, is attacking the cost of the project with advanced manufacturing methods. For example, the NLC will require the fast, cheap, and precise manufacture of 20 kilometers (12.4 miles) of linear accelerator structures. These structures will sustain the high-power microwaves on which the electrons and positrons "surf," gaining energy on their way to collision at the interaction region. The structures will be built up of two million diamond-point-machined copper cells, diffusion bonded together. Lawrence Livermore's expertise in advanced manufacturing technologies is expected to play a pivotal role in reducing costs by factors of 2 to 6 over present estimates.

While preliminary design work for the NLC is under way, a team of Livermore physicists is working to establish a center of excellence in accelerator science and technology at the 100-million-electron-volt linear accelerator (LINAC) at Livermore. The goal is to establish accelerators as a cornerstone Lawrence Livermore program by having a centralized facility for research in advanced accelerator concepts that will draw key technologies from several Laboratory directorates and programs.

An avenue of research at the LINAC that has extraordinary potential takes advantage of recent Livermore advances in high power laser technology (see the November 1995 *S&TR*, pp. 34–36, and the December 1996 *S&TR*, pp. 4–11, for descriptions of LLNL's new terawatt and petawatt lasers). Physicists plan to use a 100-terawatt (100-trillion-watt) laser built by the Laboratory's Laser Programs to explore novel acceleration methods. The results could revolutionize the design—and capability—of particle accelerators. An accelerator using laser power could in principle reduce the size of the linear accelerator at SLAC to that of a large office.

Van Bibber says that one of the primary goals of a vigorous Lawrence Livermore accelerator R&D effort is developing compact accelerators for defense, industry, and advanced research applications. Examples include developing portable accelerators to probe the interior of a small boat or truck and "interrogate" its cargo for nuclear materials or to detect land mines still buried in battle areas of Europe and Asia. Future compact electron accelerators could also make femtosecond (quadrillionth-of-a-second) x rays broadly accessible to scientists for biological or materials research.

It seems fitting that advanced accelerator technology is becoming a major focus for the Laboratory in the future. After all, it was E. O. Lawrence, Lawrence Livermore's founder, who was awarded the Nobel Prize in Physics more than 50 years ago for his pioneering work in accelerators.

—Arnie Heller

Key Words: accelerators, Accelerated Strategic Computing Initiative (ASCI), Accelerator Production of Tritium (APT), Advanced Hydrotest Facility (AHF), B-Factory, B meson, BaBar detector, Big Bang, Center for Accelerator Mass Spectrometry (CAMS), charge parity violation, LINAC, Main Injector Neutrino Oscillation Search (MINOS), Next Linear Collider (NLC), Photon–Electron New Heavy Ion Experiment (PHENIX), Stanford Linear Accelerator Center (SLAC), Stockpile Stewardship and Management Program, 100-terawatt laser.
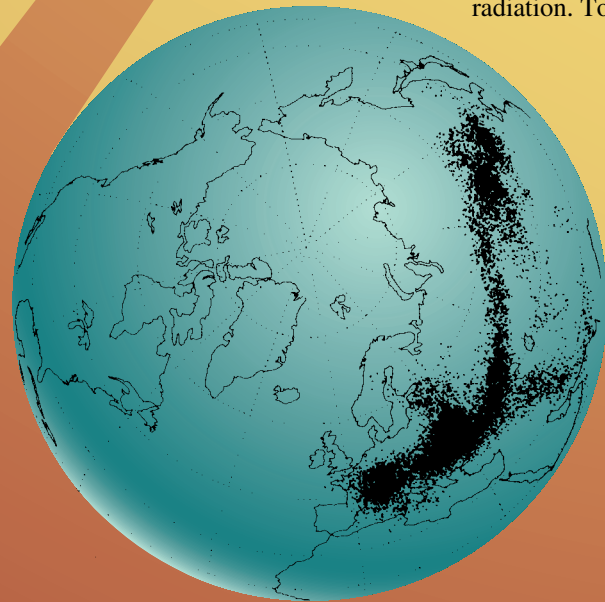
About the Scientists

MARSHALL MUGGE (left) joined the Laboratory as a physicist in 1985. He served as Assistant Division Leader in the Physics and Space Technology Directorate from 1990 to 1993. From 1977 to 1985, he was a physicist at Fermi National Accelerator Laboratory. He received his B.S. in physics and mathematics from Iowa State University and his Ph.D. in high-energy physics from the University of Colorado. He is currently deputy project leader of the Laboratory's B-Factory activities.

ROBERT YAMAMOTO is deputy division leader of the Applied Research Engineering Division of Lawrence Livermore's Engineering Directorate. He earned a B.S. in mechanical engineering from the University of California, Berkeley, and an M.B.A. from Golden Gate University in San Francisco. Yamamoto coordinates the Laboratory's engineering work for the B-Factory project.

KARL VAN BIBBER is a graduate of the Massachusetts Institute of Technology, with a B.S. in physics and mathematics and a Ph.D. in physics. He joined the Laboratory in 1985 as a senior physicist. Since July 1991, he has been group leader for High-Energy Physics and Accelerator Technology in the Physics and Space Technology Directorate. He is currently the project leader for Livermore's work on the B-Factory at the Stanford Linear Accelerator Center.

The Curious Case of the B Meson

Physicists believe a key to the matter–antimatter disparity in the universe lies in understanding an effect called charge parity violation. First observed in the 1960s, charge parity violation refers to the apparently small differences in the way that certain short-lived particles and their antiparticles decay. Many scientists, starting with the renowned Russian physicist Andrei Sakharov, have suggested that charge parity violation is the reason why the universe seems to be composed almost exclusively of matter. Or, as Stanford Linear Accelerator Center Director Burton Richter puts it, "Charge parity violation is why we're here."

Physicists think that the best way to understand the phenomenon is by studying the decay patterns of the rare B meson, a type of unstable but electrically neutral particle, and its antiparticle, the anti-B meson. The B meson consists of "anti-b" quark and a "d" quark (quarks are the fundamental building blocks of matter), while the anti-B meson consists of a "b" quark and an "anti-d" quark.

To measure the decay patterns of these extremely short-lived (1.5 trillionths of a second or 10^{-12} second) particles, investigators need a machine to produce a myriad of B mesons and anti B mesons. "B-Factories" at the Stanford Linear Accelerator Center and in Japan, both currently under construction, will provide literally millions of particles to study. In effect, says Livermore physicist Marshall Mugge, "The B-Factory will allow us to go back in time to reproduce the early conditions of the Big Bang."

At both factories, the B mesons and anti-B mesons will be created by colliding beams of electrons and positrons circling at different energies. Most of the electrons and positrons will miss each another. However, a few collisions will result in B meson–anti-B meson pairs. Because the electrons and positrons are circling at different energies, the B and anti-B mesons will be created with a push away from the point at which the two beams collide, clearly separating their decay vertices—up to a millimeter apart—and therefore making them easier to resolve.

The particle pairs will follow one of several different pathways as they decay into a host of subatomic particles like muons, leptons, neutrinos, and quarks. About one in every 1,000 pairs is expected to follow a unique pathway that results in a very special combination of particles that will signal to physicists a possible violation of charge parity. That is, these special pairs will decay to certain sets of particles at different rates.

Physicists will determine the rates of decay by measuring how far the particles have traveled from the interaction point. By knowing how fast the particles are traveling, scientists can determine the time that they existed before they decayed. The distances are exceedingly small—about a few hundred micrometers (less than one-thirty-second of an inch) in space. Subtle variations in the distribution of the distance traveled between the pairs will be evidence for charge parity violation.

Livermore physicist and B-Factory leader Karl van Bibber says that by the end of the first six months, there should be some "very interesting data" for 75 to 80 institutions worldwide to analyze. The data should enable scientists to better understand why the universe appears to contain essentially no antimatter. In so doing, they will be able to paint a much more complete and accurate picture of the fundamental nature of matter and energy.

Assessing Exposure to Radiation

Lawrence Livermore National Laboratory is a world leader in evaluating exposures to radiation, monitoring releases of radionuclides to the environment, and managing the environmental and health risks of such releases.

DAILY, every person receives "background" radiation from a variety of natural sources: from cosmic rays and radioactive materials in the Earth, from naturally occurring radionuclides in food, and from inhaling particulate decay products of radon gas. But as we have harnessed radioactivity and the power of the atom, we have created situations where we may also be exposed to manmade radiation.

Since its inception, Lawrence Livermore National Laboratory has been a world leader in evaluating exposures to radiation and their resultant risks. We use dosimetry to infer the "dose," or energy deposited in tissue, that a person has received as a result of exposure to radiation. To study past events, we have found ways to reconstruct the dose that individuals received many years earlier. We are also able to project the radionuclide retention in an individual 50 years after exposure. We can run a sampling program, do all of the analytical work, and produce assessments of the dose received. Few other facilities possess this range of capabilities.

Ultrasensitive measuring devices and sophisticated modeling techniques give us the means to quantify and extrapolate radiation exposures. We use fluorescence *in situ* hybridization (FISH), developed at Livermore, to study the effects of radiation at the cellular level. This tool gives us a better understanding of the risks associated with radiation and provides the basis for radiation safety standards worldwide.

The Laboratory has been called upon to investigate many significant exposures. We began studying the Chernobyl accident almost as soon as it happened. Dose reconstruction work related to the bombing of Hiroshima continues today with studies of nickel-63 in copper to refine the estimate of the neutron dose. We participated in a huge project to reconstruct the dose received by populations residing downwind from nuclear tests performed at the Nevada Test Site from 1951 to 1981. Another study will analyze the exposures to workers, children, and area residents at Mayak in the former Soviet Union, where plutonium and other nuclear weapons materials were produced.

Workers, including those at Livermore, who handle significant quantities of radioactive material as part of their jobs are routinely monitored. We have combined those data with information on monitored workers extending back to the Manhattan Project to update and revise the models that dosimetrists throughout the world use to describe the retention of radioactive substances in the body. In another project, our dose assessment and projection efforts will help the residents of Bikini Atoll, whose homeland was contaminated by atmospheric nuclear testing, return home soon.

We also work with numerous federal agencies to avoid nuclear accidents and to be prepared for them when they do occur. Our Atmospheric Release Advisory Capability (ARAC—see pp. 18–20) is pre-eminent in assisting with advanced planning for potentially hazardous activities, staff training, and emergency response.
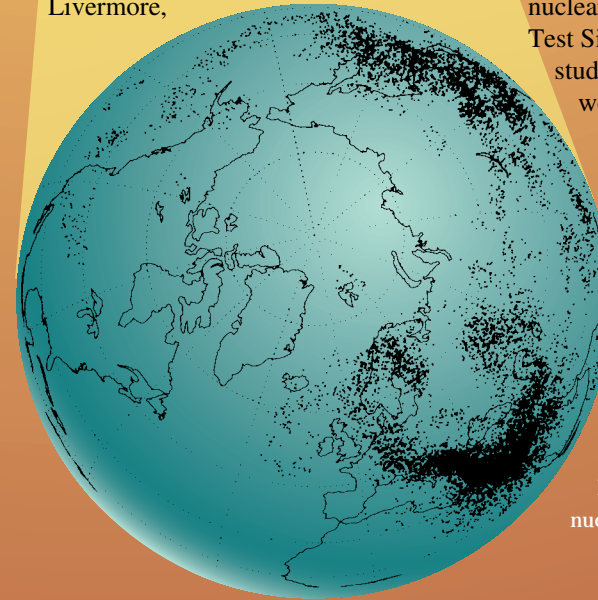
Figure 1. Plots prepared by our Atmospheric Release Advisory Capability showing how the clouds of radioactive material spread around the Northern Hemisphere at (from upper left) 2 days, 4 days, 6 days, and 10 days after the initial nuclear accident at Chernobyl.

The Chernobyl Accident

Shortly after the April 1986 Chernobyl nuclear power plant accident, the Department of Energy assembled a task force, which included a Livermore team led by Lynn Anspaugh, to assess the accident's biological effects. Reconstructing the dose posed special problems. For many months after the accident, the source term—the amount and kinds of radionuclides released—was not revealed by the Soviet Union and so had to be inferred.

One of the earliest samples of Chernobyl's radioactive effluent was an air sample taken in Finland nearly two days after the release. From the ratio of the activities of the dozens of radionuclides in this sample, the known half-lives of the nuclides, and the known radioactive products ("daughters") of these nuclides and their activities and half-lives, we could calculate what the radionuclide mixture in the air would be at any subsequent (or earlier) time.

Then, by adding measurements of the external gamma- exposure activity rates or radionuclide deposition on the ground, we could calculate what the external exposure rate and dose from each radionuclide would be to individuals, both at the time of the sampling and well into the future. Once we reconstructed the major pathways by which these radioisotopes could enter individuals via the ingestion of contaminated food, we could calculate what their internal doses would be. Finally, from the external and internal dose, we estimated the possible biological effects on individuals and populations of the radioactive release using health-risk models (see box pp. 18–20).

Calculating the internal dose is generally the most difficult part of a dose reconstruction problem because of the many available mechanisms by which radiation can enter the human body. We used PATHWAY,[1] the model that was developed for our dose reconstruction work at the Nevada Test Site, to calculate radiation dose resulting from ingested radionuclides.

Another consideration in this work was the sheer size of the Chernobyl release and the complex global circulation pattern the radioactive plume followed. ARAC's modeling efforts showed that Chernobyl produced three separate clouds of radioactivity that went in different directions. The radiation released in the initial explosion rose to an altitude of 1.5 to 7.5 kilometers (0.9 to 4.7 miles) and went east and southeast, whereas the radiation released from the resulting fire stayed below 1.5 kilometers and headed northwest (see Figure 1). Our work showed that the dose to individuals and the collective dose to populations varied considerably from one country to another. Only within the immediate vicinity (30 kilometers, or 18.6 miles) of Chernobyl were the biological effects expected to be large enough to be detected epidemiologically.[2]

More recently, the incidence of childhood thyroid cancer has risen dramatically in the areas of Belarus, Ukraine, and Russia nearest Chernobyl, prompting a renewed interest in reconstructing the dose because of iodine-131, which collects in the thyroid gland. However, iodine-131 has a half-life of only eight days and thus had decayed by the time most soil measurements were taken. Ordinarily, iodine-131 deposition can be estimated from the cesium-137 level in soil. But the explosion and subsequent fire at Chernobyl produced releases with different relative quantities of the two radionuclides, and the debris then traveled in different directions. The ratio of cesium-137 to iodine-131 was thus not the same at different locations.

In a project for Belarus, Livermore's Tore Straume, Lynn Anspaugh, and others developed a method using accelerator mass spectrometry (AMS—see box pp.18–20) to measure the deposition in soil of the isotope iodine-129, which is much longer lived but more difficult to measure than iodine-131. Initial measurements of the ratio of iodine-129 to iodine-131 indicated that the ratio is constant over different locations, making it possible to reconstruct the iodine-131 dose from iodine-129 soil measurements.[3]

The next step will be to take enough soil samples to develop an "iodine map" for all of Belarus to determine the correlation between thyroid cancer and iodine deposition. This information will be enormously useful for future epidemiological studies, for establishing thyroid cancer screening procedures, and for dose reconstruction in other areas of the country.

Assessing Worker Exposure

When x rays were first used in the late 19th century, skin burns were observed, and in the 1920s, scientists discovered that radiation exposure caused genetic mutations on a cellular level. When the Manhattan Project began in the 1940s, radiation protection was considered important, but standards and established practices did not exist. Scientists did not know how to evaluate the dose to workers from internal depositions of radioactive materials because there was limited information on the biological effects of radiation and how the body retains radioactive substances.

Since then, research has provided better information about biological effects and retention of radionuclides, with a consequent improvement in radiation protection standards and practices. Today, for example, workers at Livermore's Plutonium Facility follow strict procedures.

Since the 1940s, radiation workers have been routinely monitored using bioassay techniques—both *in vivo* (e.g., whole-body and lung counters) and *in vitro* (e.g., urine, feces, hair, saliva, and blood samples). (See Figure 2.) From these bioassay results, internal doses are derived using biokinetic models (see box pp. 18–20) and dose-estimation techniques. From the resulting doses, the worker's level of exposure is estimated and compared with radiation protection standards.

Because the biokinetic models, dose-estimation techniques, regulatory standards, and reporting requirements have evolved over time, today we have a vast number of dose estimates that are difficult to compare from one time period to another. One task of our Internal Dosimetry Assistance Group, led by David Hickman, is to evaluate and reconcile these past data. This is a huge task involving more than 50 years of bioassay data, sometimes with daily sample frequencies.

The Internal Dosimetry Assistance Group also performs work for outside organizations. One recent study of workers at another facility involved employees who had unintentionally received intakes of phosphorus-32, an isotope commonly used in biomedical research. Large amounts of *in vivo* and *in vitro* bioassay data were collected to make a determination of the internal dose. This project also supplied enough data to derive a new biokinetic model for phosphorus-32 based on human metabolic data. Many biokinetic models are based on animal data because those are the only data available, but human data, when available, tend to be more valuable.

Using our accumulated information, we have also been able to produce a standard method of evaluating worker exposure to radionuclides independent of the time the exposure occurred. We have used this information to derive new human-based, rather than animal-based, biokinetic models that dosimetrists can use as default radionuclide retention assumptions when bioassay data are not available.

The Marshall Islanders

Fallout from nuclear tests between 1946 and 1958 at Bikini and Enewetak atolls contaminated several islands of the Northern Marshall Islands in the western Pacific Ocean. In particular, the BRAVO Test on March 1, 1954, contributed heavily to the contamination at Bikini Atoll and at other atolls to the east. Relocated to other islands prior to the tests, the people of Bikini and Enewetak atolls have wanted to return home ever since. As part of an evaluation of resettlement options, our team led by

Figure 2. A variety of detectors are used for *in vivo* measurements of radionuclide levels. (a) shows Nancy Allen, a training instructor in the Hazards Control Department, lying on a scanning-bed, whole-body counter. Its four germanium detectors measure the distribution of high-energy, photon-emitting radionuclides. In (b), 15.2-centimeter- (6-inch-) square Phoswich detectors are positioned over her lungs, and in (c), low-energy germanium (LEGe) detectors also cover her lungs. Both the Phoswich and LEGe detectors measure low-energy, photon-emitting radionuclides in such organs as the lungs, thyroid, liver, kidney, bone, and lymph nodes. The LEGe detector best identifies specific radionuclides, while the Phoswich measures a larger area and provides more accurate readings of nuclide activity levels. These detectors are housed in an underground room built with very thick shielding to eliminate as much background radiation as possible.

(a)

(b)

(c)

Tools for Assessment

Lawrence Livermore comes to the task of dose assessment with a full complement of time-tested tools. Many have been evolving since the days of the Manhattan Project, while others, like computer modeling, are much newer. In addition to the tools described below, we also apply industry-standard radiation detection and bioassay techniques as needed.

Biodosimetry

Biological dosimetry—or biodosimetry—measures the effects of radiation exposure on biological organisms. The goal of biodosimetry is to quantify how an exposure is distributed within an organism when the exposure is known or, when the exposure is not known, to "back in" to the dose from observation of the organism.

Biodosimetry involves establishing a dose-response relationship or following the dose as it is distributed throughout an organism. Dose measurements can be made directly, such as by measuring the radiant energy emitted with a whole-body counter, or indirectly by measuring the dose's biological effects. The biological parameters most often relied on are survival, birth defects, chromosomal abnormalities, chromosome breakage, and chemical changes.

To help us understand the effects of low doses of radiation on people and animals, at Livermore we use the sensitive techniques of chromosome painting and accelerator mass spectrometry.
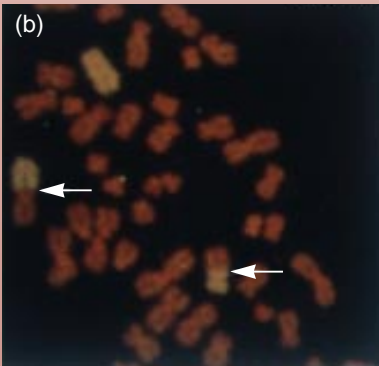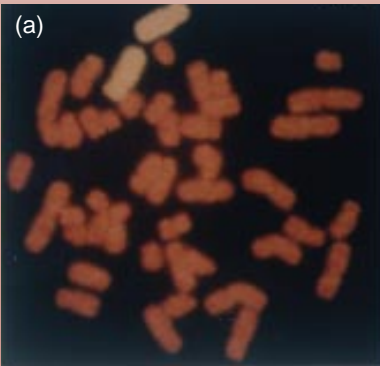
Chromosome painting using fluorescence *in situ* hybridization (FISH) is a technique developed at Livermore for studying chromosomal changes in cells. Chromosomal DNA is labeled with chemicals that can be stained to produce vivid colors; the colors allow the different chromosomes to be readily distinguished so that chromosomal rearrangements (such as translocations) can be identified. (See the images below.) Studies have shown that these translocations are stable over time,* which makes FISH particularly useful for dose reconstruction. For example, a worker who accidentally inhaled tritium oxide in 1986 was re-evaluated six years later using translocations measured by FISH. The dose, estimated biodosimetrically, confirmed the dosimetry results obtained immediately after the accident.

Accelerator Mass Spectrometry

Accelerator mass spectrometry (AMS) is used to detect a variety of isotopes at very low concentrations. Its sensitivity is typically a million times greater than that of conventional mass spectrometry. AMS was first used for dose reconstruction in 1979 to analyze concrete and other mineral materials from Hiroshima for chlorine-36 produced by the bomb. Today, Livermore's Center for Accelerator Mass Spectrometry, under the leadership of Acting Director Ivan Proctor, is one of the few in the world used for dose reconstruction purposes. (See the photo p. 19.)

Mass spectrometry is used to determine the mass of an atomic species or molecular compound. AMS, as it is applied at Livermore, adds three steps to mass spectrometry. After the initial acceleration to kilovolt energies and the separation of the ion beam by mass to electrical charge, a second acceleration of millions of volts is applied. Then the ion beam is stripped to a charge state where at least three electrons are removed from the atoms of interest, thus destroying all molecular species. The resulting

(a) Two chromosome 4s from a normal cell have been stained yellow using FISH (fluorescence *in situ* hybridization), while the other chromosomes have been counterstained red. (b) After irradiation, one normal chromosome 4 is visible, while the other has broken into two pieces and translocated to the corresponding pieces from a broken red chromosome (arrows).

* J. N. Lucas *et al.* "The Persistence of Chromosome Translocations in a Radiation Worker Accidentally Exposed to Tritium,"*Cytogenetics and Cell Genetics* **60**, 255–256 (1992); and J. N. Lucas *et al.,* "Stability of the Translocation Frequency Following Whole-Body Irradiation Measured in Rhesus Monkeys," *International Journal of Radiation Biology* **70**, 309–317 (1996).

positive ion beam is further accelerated through a third stage of millions of volts. Finally, the isotope has its mass, energy, velocity, and charge redundantly determined to remove background events associated with the instrument.

Livermore's pioneering use of AMS in carbon-14 measurements for biomedical applications led to applications involving other radioisotopes of biological interest, such as tritium (hydrogen-3), aluminum-26, calcium-41, and iodine-129. Today, for example, tritium can be detected at the level of 0.1 parts per quadrillion (10^{15}) and iodine-129 at 40 parts per quadrillion.

A project led by Laboratory scientist Tore Straume is using AMS's advanced separation techniques to measure levels of nickel-63 in copper samples from Hiroshima. These measurements, which sample a different energy slice of the bomb's neutron output, will help resolve discrepancies in earlier, less sensitive measurements of neutrons near the bomb's hypocenter and lead to a more accurate dose assessment.

Biokinetic Models

Livermore was a pioneer in the development of biokinetic models to describe the retention of a radioactive substance in the body or an organ as a function of time. (Biological kinetics, or biokinetics, describes the dynamics of the body—e.g., inhalation, exhalation, absorption, adsorption, metabolism, excretion—any of which may affect the retention of a substance.) Some biokinetic models are specific for a particular organ while others describe whole-body systemic retention.

Biokinetic models are published as internationally accepted default models for use by laboratories. Scientists use the fractional retention from the model coupled with bioassay measurements to derive an estimate of intake. Biokinetic models are also used to project a worker's internal dose for up to 50 years after an intake.

Livermore's Internal Dosimetry Assistance Group has been responsible for updating many biokinetic models. Workers who handle radioactive materials have been regularly monitored since the inception of the Manhattan Project, supplying a wealth of information about individuals and groups of people. The accuracy of internal dose projections 50 years after an intake depends on the adequacy of the biokinetic models used for the projection. We use biokinetic models to calculate the expected results from bioassays over 50 years, which are then compared with measured bioassay levels in the years following an intake. With these data and within the accuracy of the models, we can determine whether additional intakes occurred during the working career of the employee.
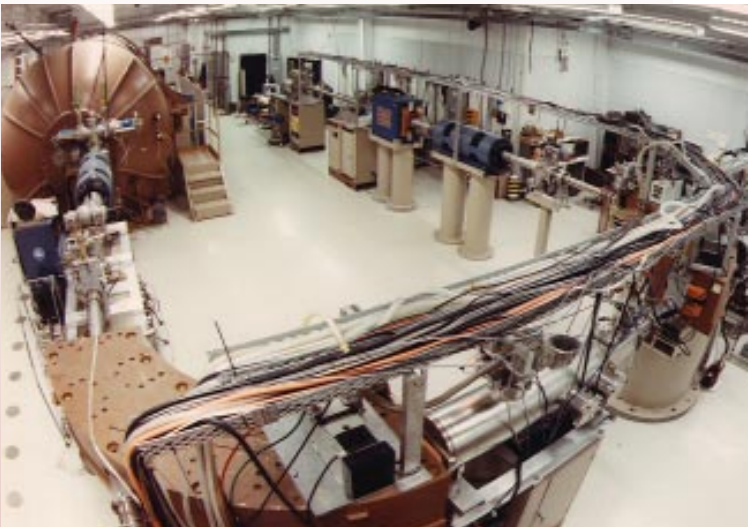
The high-energy spectrometer and particle counter at Livermore's Center for Accelerator Mass Spectrometry.

Likewise, the projection of bioassay levels makes it possible to determine the adequacy of the biokinetic models for humans and to refine these models as data become available, thus improving internal dose projections. Our model-development work provides realistic biokinetic parameters that are used by dosimetrists all over the world to estimate doses to anyone who has been exposed to radioactive materials.

ARAC

Livermore's Atmospheric Release Advisory Capability (ARAC), under Thomas Sullivan, has a very clear charter: to address any kind of radiological release anywhere in the world that could affect a U.S. citizen. Over the years, ARAC has added toxic material modeling and analysis to its repertoire and has helped to assess potential problems arising from chemical and biological warfare conditions.

ARAC's physical resources are built around the AEROS (ARAC Emergency Response Operating System) computer network. Central computers at Livermore support user workstations at 40 designated facilities, continuously exchanging real-time, site-specific meteorological information, local data, and central system–prepared advanced model calculations.

To produce simulation models that show the movement, extent, and magnitude of atmospheric releases, ARAC's experts

also rely on three-dimensional atmospheric transport and dispersion models, graphical displays, and extensive databases (e.g., geophysical data, radionuclide and toxic-substance properties, dose conversion factors, topography for any part of the world, a detailed weather network). ARAC can model a radiological accident in the U.S. within 15 to 60 minutes. HOTSPOT, another atmospheric dispersion tool developed at Livermore, can be run for initial assessment in a few minutes on a palm-sized computer.

ARAC has received international recognition for its success in responding to and assessing radioactive atmospheric release accidents throughout the world. Some of ARAC's more notable responses include the re-entry of the U.S.S.R.'s nuclear-powered Cosmos-954 satellite into the atmosphere over Canada (1978), the Three Mile Island accident in Pennsylvania (1979), the accidental release of uranium hexafluoride from the Sequoyah Fuels Facility in Oklahoma (1986), as well as the Chernobyl

reactor accident in the former Soviet Union. Other responses involved nonradioactive releases, including the oil fires in Kuwait and the eruption of Mount Pinatubo in the Philippines, both in 1991.

In an effort to be prepared for accidents like Chernobyl, for nuclear terrorism, and for other radiological events, ARAC also provides an emergency response and assessment service to many federal agencies. One aspect of this service is preparing assessments of the atmospheric dispersal of radionuclides from likely accidents so that planners can put in place the resources to deal with them. ARAC has done many such studies for facilities at the Nevada Test Site, at LLNL, and at other DOE sites.

ARAC also provides input to and participates in a variety of training exercises. We can model accident scenarios provided by a client by using real-time meteorology at the client's site, thus enhancing the realism of the exercise. ARAC can also "create" special meteorology to test a particular aspect of a site's response.

(continued from page 17)

William Robison began a radioecology and dose assessment program in 1973 that continues today.

We have taken nearly 70,000 samples of edible food crops, vegetation, soil, water, marine life, and animals to evaluate the various exposure pathways for radiological dose. At several atolls, we have also completed measurements of external gamma exposure and studies of the extent to which the resumption of human activity would cause nuclides in the surface soil to be resuspended into the air and thus inhaled. Results indicate that the terrestrial food chain is the most significant exposure pathway, with external exposure to gamma radiation the next most significant.

Combining the radionuclide inventory from the samples, a diet model for the population, and biokinetic models (see box on pp. 18–20), we have determined that the dose from the ingestion pathway contributes 70 to 90% of the total estimated dose. Cesium-137 would produce 96% of the estimated dose for

returning residents, mostly through uptake from the soil to terrestrial food crops. Inhalation accounts for about 1% of the estimated dose, according to surface soil levels and resuspension studies.

Our dose assessments indicate an estimated maximum annual effective dose at Bikini Island of 4 millisieverts.* This is based on a resettlement date of 1999 and assumes that no remedial measures are taken and that imported foods, which are now an established part of the diet, continue to be available. (In comparison, the average annual U.S. dose from all forms of natural background radiation is about 3 millisieverts.)

To reduce cesium-137 in food crops, we recommended treating them with potassium fertilizer, which would reduce the uptake of cesium-137 and therefore the ingestion dose to about 5% of pretreatment levels. Removing the top 40 centimeters (15.7 inches) of soil over the entire island would also

effectively reduce the potential dose, but at a high environmental and dollar cost. If the top 40 centimeters of soil were removed in just the housing and village areas and the rest of the island treated with potassium fertilizer, the maximum annual effective dose would be reduced to 0.41 millisieverts, which is comparable to the effective dose from two chest x rays.

This information has been provided to the Marshall Islanders, but they have not yet decided how they wish their islands to be rehabilitated. In the meantime, sampling continues (see Figure 3) with a focus on further characterization of the sampled areas, more systematic sampling of the atolls, and countermeasures to reduce doses.[4]

The Job Ahead

In all of our dose assessment work at Livermore, we strive to understand not only the effects of high levels of exposure from atomic weapons and reactor accidents but also of very small

exposures. And as we develop new methods and tools, our dose estimates can be made increasingly accurate. For example, a revised biokinetic model for a particular organ may prompt a new retrospective study to update an internal dose that had been based on an old model. The more we know about the effects of radiation, the better we can prepare for future accidents, educate our workers and the public about radiation's risks, and manage those risks to mitigate them.

—Katie Walter

Key Words: accelerator mass spectrometry, Atmospheric Release Advisory Capability (ARAC), biodosimetry, biokinetic model, BRAVO test, Chernobyl accident, dose reconstruction, dose assessment, FISH (fluorescence *in situ* hybridization), Marshall Islands, prospective dosimetry, worker exposure.

Figure 3. Livermore environmental scientists in the field at Bikini Island are collecting coconut samples at one of the experimental potassium fertilizer plots.

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About the Scientists

Radiation dose assessment at Livermore is multidisciplinary in a broad and deep sense. The scientists whose work contributed to the Laboratory's dose assessment capability reported on in this article are pictured left to right: TORE STRAUME, WILLIAM ROBISON, JOE LUCAS, THOMAS SULLIVAN, and LYNN ANSPAUGH. (Not shown are IVAN PROCTOR, and DAVID HICKMAN.) Their expertise and that of the groups they lead span a variety of disciplines—biology and genetics, biodosimetry, dose reconstruction, accelerator mass spectrometry, radioecology, biokinetic modeling, atmospheric dispersion and transport modeling, and emergency preparedness and response. Their scientific training and experience represent a Laboratory capability in dose assessment recognized for its excellence worldwide.

* Millisievert is a Standard International Unit for measuring dose to humans; 1 millisievert equals 100 millirems.

The Next Generation of Computer Storage

WORK recently began at Lawrence Livermore National Laboratory and sister Department of Energy laboratories on the Accelerated Strategic Computing Initiative (ASCI), one of the largest supercomputing projects of all time. A major component of DOE's science-based Stockpile Stewardship and Management Program, ASCI's computational modeling and simulation capabilities will be used to assess the safety, security, and reliability of our nuclear stockpile.

ASCI's systems will soon be performing a trillion (tera or 10^{12}) floating-point operations per second (flops) requiring memories of tens of trillions of bytes, which is well beyond the range of existing supercomputers. By 2004, ASCI systems will be performing in the 100-teraflops range. These machines will require systems that may be called on to store a quintillion or 10^{18} bytes (an exabyte), which is over ten thousand times beyond the capability of today's supercomputing storage systems. In addition, the transfer rates between these massive processing and storage systems will have to be on the order of tens to hundreds of billions of bytes per second. Achieving a balance between supercomputer processing and memory capacities and storage capabilities is critical not only to the success of ASCI but also to other high-end applications in science modeling, data collection, and multimedia.

Recognizing this coming need and the long-term effort required to achieve this balance, the National Storage Laboratory (NSL) was established in 1992 to develop, demonstrate, and commercialize technology for storage systems that serve even the most demanding supercomputers and high-speed networks. The

With typical large-scale data storage systems today, general-purpose computers act as storage servers connecting storage units with client systems. As storage rates and capacities increase, the storage servers increase in size and cost, and bottlenecks occur in the transfer of stored data to client systems.
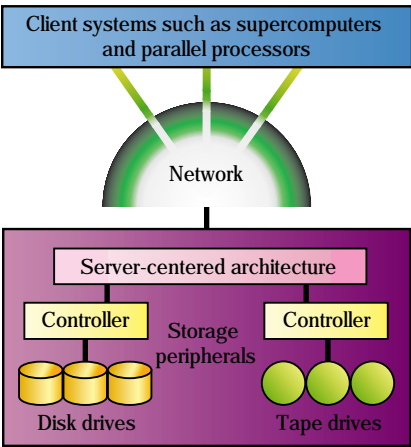
NSL consisted of an advanced storage hardware testbed at Livermore and distributed software development partners. It involved more than 20 participants from industry, the Department of Energy, other federal laboratories, universities, and National Science Foundation supercomputer centers. The NSL collaboration was based on the premise that no single organization has the ability to confront all of the system-level issues that must be resolved in a timely manner for significant advancement in high-performance storage system technology. Lawrence Livermore and its sister DOE laboratories play leadership roles in developing high-performance storage systems because of their long history of development and innovation in high-end computing—of which storage is a critical component—in order to meet their national defense and scientific missions.
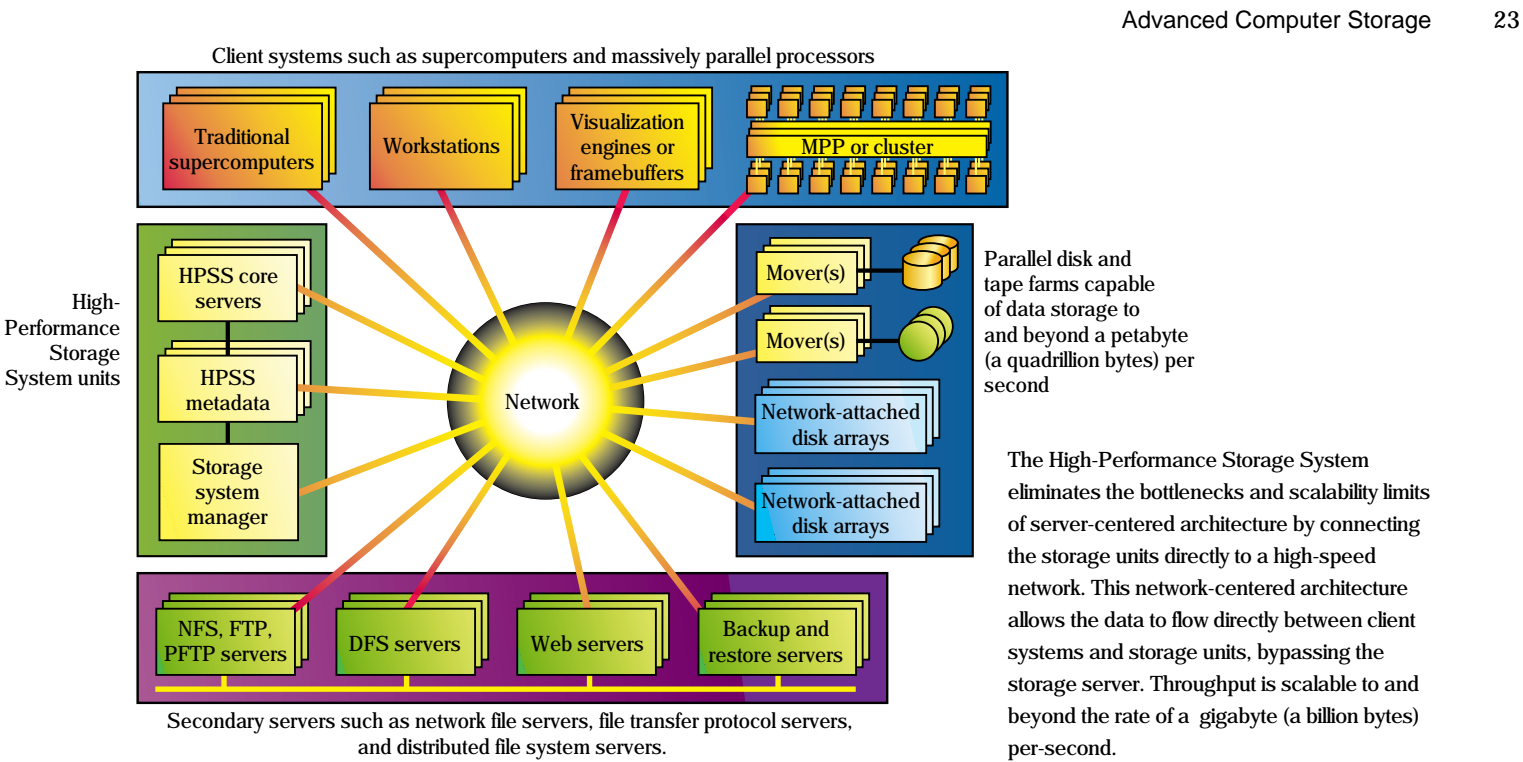
High-Performance Storage Systems

The High-Performance Storage System (HPSS) software development project grew out of NSL work. A major requirement for HPSS was that it be "scalable" in several dimensions—to allow huge capacities and transfer rates and to support many distributed systems and users. The system also had to be reliable, secure, and portable to many computing platforms and manageable by a small staff.

Work completed by the NSL had shown that HPSS could only be successful if it were based on a network-centered design. Typically, large-scale data storage has been handled by general-purpose computers acting as storage servers that connect to storage units such as disks and tapes (see figure below, left). The servers act as intermediaries in passing data to client systems like workstations or supercomputers on their network. As requirements for storage device data rates and capacities increase, the storage server must handle even more data faster. As data rates increase for storage devices and communications links, the size of the server must also increase to provide the required capacity and total data throughput bandwidth. These high data rates and capacity demands tend to drive the storage server into the mainframe class, which can be expensive to purchase and maintain and can have scalability limits.

If the storage software system and storage devices are instead distributed over a network, control of the storage system can be separated from the flow of data (see figure, p. 23). The bottleneck is removed, allowing more rapid data transmission and scalability of performance and capacity. Workstation-class systems used as storage servers provide the high-performance required and reduce the cost for storage server hardware in the bargain.

Focus on the Network

Operating on a high-performance network, the High-Performance Storage System uses a variety of cooperating distributed servers to control the management and movement of data stored on devices attached directly to the network. HPSS is designed to allow data to be transferred directly from one or more

Client systems such as supercomputers and parallel processors

Network

Server-centered architecture

Controller   Storage peripherals   Controller

Disk drives   Tape drives

Client systems such as supercomputers and massively parallel processors

Traditional supercomputers   Workstations   Visualization engines or framebuffers   MPP or cluster

High-Performance Storage System units

HPSS core servers

HPSS metadata

Storage system manager

Network

Mover(s)

Mover(s)

Network-attached disk arrays

Network-attached disk arrays

Parallel disk and tape farms capable of data storage to and beyond a petabyte (a quadrillion bytes) per second

NFS, FTP, PFTP servers   DFS servers   Web servers   Backup and restore servers

Secondary servers such as network file servers, file transfer protocol servers, and distributed file system servers.

The High-Performance Storage System eliminates the bottlenecks and scalability limits of server-centered architecture by connecting the storage units directly to a high-speed network. This network-centered architecture allows the data to flow directly between client systems and storage units, bypassing the storage server. Throughput is scalable to and beyond the rate of a gigabyte (a billion bytes) per-second.

disk or tape controllers to a client once an HPSS server has established a transfer session. Its interfaces support parallel or sequential access to storage devices by clients executing parallel or sequential applications. HPSS can even manage data transfers in a situation where the number of data sources and destinations are different. Parallel data transfer is vital in situations that demand fast access to very large files and to reach the high data transfer rates of present and future supercomputers.

All aspects of HPSS are scalable so that the storage system can grow incrementally as user needs increase. The parallel nature of HPSS is one key to its scalability. For example, if a system has a storage device that can deliver 100 megabytes (100 million bytes) per second but a gigabyte (a billion bytes) per second is needed, then 10 devices in parallel, controlled by HPSS software, can be used to "scale up" to the new requirement. With this design, HPSS will be able to handle almost unlimited storage capacity, data transfer rates of billions of bytes per second and beyond, virtually unlimited file sizes, millions of naming directories, and hundreds to thousands of simultaneous clients.

HPSS uses several mechanisms to ensure data reliability and integrity. An important one is the use of transactions, which are groups of operations that either take place together or not at all. The problem with distributed servers working together on a common job is that one server may fail or not be able to do its part. Transactions assure that all servers successfully complete their job or the function is aborted. Although transactional integrity is common in relational data management systems, it is new in storage systems.

HPSS was designed to support a range of supercomputing client platforms, operate on many vendors' platforms, and use industry-standard storage hardware. The basic infrastructure of

HPSS is the Open Software Foundation's Distributed Computing Environment because of its wide adoption among vendors and its almost universal acceptance by the computer industry. The HPSS code is also available to vendors and users for transferring HPSS to new platforms.

The principal HPSS development partners are IBM Worldwide Government Industry and four national laboratories—Lawrence Livermore, Los Alamos, Oak Ridge, and Sandia. There have been two releases of HPSS thus far, and IBM is marketing the system commercially. HPSS has already been adopted by the California Institute of Technology/Jet Propulsion Laboratory, Cornell Theory Center, Fermi National Accelerator Laboratory, Maui High-Performance Computer Center, NASA Langley Research Center, San Diego Supercomputer Center, and the University of Washington, as well as by the participating Department of Energy laboratories.

In combination with computers that can produce and manipulate huge amounts of data at ever-increasing rates, HPSS's scalable, parallel, network-based design gives users the capability to solve problems that could not be tackled before. As computing capacity and memory grow, so will HPSS evolve to meet the demand.

—Katie Walter

A Powerful New Tool to Detect Clandestine Nuclear Tests

Experiments with the Laboratory's new method of detecting clandestine nuclear tests were conducted on the rocky Rainier Mesa at the Nevada Test Site during periods of low atmospheric pressure, mainly at the beginning of storms, so that tracer gases could rise toward the surface through natural faults and fractures.

WHEN President Clinton and other world leaders signed the landmark Comprehensive Nuclear Test Ban Treaty last September, they served notice that any signatory nation trying to conceal an underground nuclear test would have to elude a vigorous international verification program armed with the latest monitoring technologies. Thanks to the work of a multidisciplinary Lawrence Livermore team, the international community now has a powerful new forensic tool to help enforce the treaty by detecting even deeply buried clandestine nuclear tests.

Under the terms of the treaty, which bans all nuclear weapons test explosions, a system of verification and inspection will be administered by the Comprehensive Test Ban Treaty Organization in Vienna, Austria.

Lawrence Livermore scientists have long played an important role in providing monitoring technologies in support of nuclear treaty verification and on-site inspection. The latest Livermore technology is based on the discovery that minute amounts of rare, radioactive gases generated in underground nuclear detonations will migrate toward the surface along natural fault lines and earth fissures.

Livermore geophysicist Charles Carrigan led the team that included physicists Ray Heinle, Bryant Hudson, and John Nitao and geophysicist Jay Zucca. With the help of results from earlier studies, they theorized that highly sensitive instruments might detect telltale radioactive gases rising during periods of barometric low pressure through natural fissures in the ground above the blast. To test the hypothesis, the team obtained two gases, 0.2 kilograms (7 ounces) of helium-3 and 50 kilograms (110 pounds) of sulfur hexafluoride, as tracers. These nonradioactive gases are ideal tracers because they are present in very low quantities in the natural environment.

As the photo on p. 25 shows, the bottles containing the gases were placed with a 1.3-kiloton charge of chemical explosives into a mined cavity that was 15 meters (50 feet) in diameter and 5 meters (17 feet) high. The cavity was located 400 meters (1,300 feet) below the surface, two to three times deeper than that required for a similar sized underground nuclear test. A somewhat shallower detonation, says Carrigan, might have produced a collapse crater or extensive fractures connecting the cavity with the surface, both telltale signs of an underground explosion. Hence, clandestine tests would very likely be conducted at the greater depth to avoid easy detection of treaty violations.

Simulating a Nuclear Test

The detonation, known as the Non-Proliferation Experiment, occurred on September 22, 1993, in the rocky Rainier Mesa of the Nevada Test Site, where some of the nation's nuclear tests were conducted until a testing moratorium went into effect in 1992. The chemical explosion simulated a 1-kiloton underground nuclear detonation, which, as expected, did not produce any visible new cracks in the Earth.

Over the year and a half following the blast, team members, including technical support personnel from Test Site contractors EG&G and REECo, collected nearly 200 samples of subsoil gases for measurement. At some sampling stations, sampling tubes were driven into the ground to depths of 1.5 to 5 meters (5 to 16 feet) along fractures and faults. At other stations, tubes were simply placed beneath plastic sheeting that was spread on the ground to trap rising soil gases and to limit atmospheric infiltration (see photo, p. 26).

The first positive finding came 50 days after the explosion, when sulfur hexafluoride was detected in fractures along a fault. Interestingly, the much lighter helium-3 showed up 375 days—more than a year—following the explosion. Both gases were first detected along the same natural fissure within 550 meters (1,800 feet) of the blast site.

Over the course of the extended sampling period, virtually all the samples yielding concentrations of the two tracers appeared along natural faults and fractures in the mesa during periods of low atmospheric pressure, mainly at the beginning of storms. The low pressure accompanying storms, says Carrigan, makes it possible for the gases to move toward the surface along the faults. Although over the course of a year the number of low-pressure days equal the number of high-pressure days, the gases are eventually drawn upward. "There's a ratcheting effect," he explains. "The gases don't go back down as much as they go up." (See the simulation on p. 26.)

Carrigan notes that it is counterintuitive that helium-3 takes so much longer to make its way up natural fissures than sulfur hexafluoride, which is 50 times heavier. Computer models developed at Livermore showed that this result occurred because most of the heavier sulfur hexafluoride gas moved directly up the rock fractures. In contrast, the helium-3 diffused readily into the porous walls of the rocks as it slowly moved upward toward the soil surface. Critical to determining why helium-3 behaved as it did was Bryant Hudson's analysis of helium-3 in Livermore's noble gas laboratory, where he used mass spectrometry to measure the presence of helium-3 in soil-gas samples down to parts per trillion.

Modeling the Detonation

Carrigan and Nitao modeled the experiment using a porous-flow simulation software called NUFT (Non-Isothermal Unsaturated Flow and Transport) developed at LLNL by Nitao. In attempting to make the simulation as realistic as possible, the team used actual barometric pressure variation data from the Rainier Mesa weather station. The simulation showed the two gases moving at different rates toward the surface following the detonation. The calculated arrival times at the surface for both tracers were in excellent agreement with the data.

Given the good agreement between the computer model and the observations, the team then used NUFT to simulate the gases released from an underground 1-kiloton nuclear test under atmospheric conditions similar to those that followed the 1993 Non-Proliferation Experiment. The software was used to predict the arrival of detectable concentrations of the rare gases argon-37 and xenon-133 at 50 and 80 days, respectively, after the detonation.

These two isotopes are ideal indicators of nuclear explosions because they are not produced naturally in significant quantities; thus, background levels are extremely low. Also, their short half-lives of 34.8 days and 5.2 days can be used to infer how recently an event had occurred. Other, more long-lived isotopes might still be present in the environment from decades-old tests and would tend to muddy the conclusions of investigators trying to determine whether a clandestine test had recently occurred.

The successful confirmation of the experiment by computer simulation implies that sampling of soil gases for rare, explosion-produced radioactive tracer gases at the surface near a suspected underground test can be an extremely sensitive way

A bottle of sulfur hexafluoride gas is separated from the explosives in a mined test cavity to prevent thermal decomposition of the tracer gas during detonation.
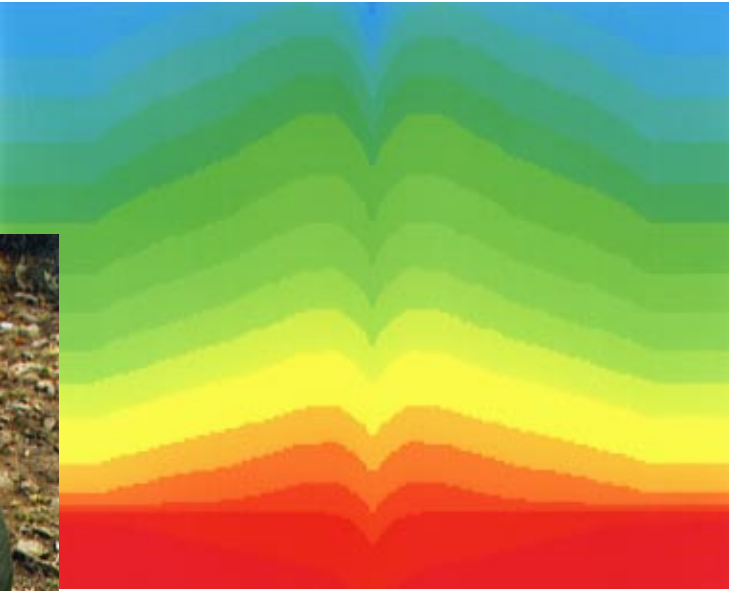
A crew of scientists from Livermore and the Nevada Test Site collect soil-gas samples from tubes inserted to a depth of 5 meters (16 feet) in soils that cover rock containing geologic faults and fractures. The soil gases were detected following a contained, 1-kiloton, underground chemical explosion 400 meters (1,300 feet) beneath Nevada's Rainier Mesa.

Using Livermore's NUFT (Non-Isothermal Unsaturated Flow and Transport) simulation software, the team was able to model gases moving toward the surface following detonation. Shown is a "rainbow" simulation of barometric "ratcheting" of trace gas in the porous walls of a 300-meter- (985-foot-) long, 0.001-meter- (0.03-inch-) wide vertical fracture (centerline of graphic). Concentration decreases from red near the detonation to blue at the surface as surface pressure variations cause the tracer gas to move up and down the fracture until it eventually reaches the surface.

to detect nearby underground nuclear explosions that do not fracture the surface. As a result, says Carrigan, an on-site inspection has a good chance of finding conclusive evidence for a clandestine nuclear explosion for several months afterward.

Putting Treaty Evaders on Notice

"If detected, the radioisotope signals would be unequivocal," according to Bryant Hudson. "They would put treaty evaders on notice that they risk detection if they try to explode a nuclear device underground. We can't absolutely guarantee there won't be cheating, but we've made it more difficult."

Carrigan points out that because of political considerations, it may take some time to get a country to agree to an on-site inspection under the terms of the test ban treaty. The thinking of many experts has been that such inspections need to be conducted within a few days to capture evidence of a test. The Livermore team's work, however, shows that waiting weeks or even months to detect rare gases is not a problem and may well be advantageous, because the gases need time to arrive at the surface.

Team members caution that searching for tracer gases is only one of many detection tools. Other methods that might be used at a suspected test site include analyzing the printouts of seismographs for aftershocks from an explosion, looking for explosion-induced stress in plants and trees, drilling for explosion debris, examining the earth for fractures and craters, and searching for pipes and cables leading underground.

In discussing the work of the team, Carrigan attributes its accomplishments to a confluence of Lawrence Livermore strengths in computer simulation, geophysical theory, nuclear test containment, and radiochemistry. "Interdisciplinary collaboration made this work possible," he says.

—*Arnie Heller*

Key Words: Comprehensive Nuclear Test Ban Treaty, nuclear proliferation, nuclear treaty verification, NUFT (Non-Isothermal Unsaturated Flow and Transport).

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Patents and Awards

Patents

Patent issued to	Patent title, number, and date of issue	Summary of disclosure
John W. Elmer Alan T. Teruya Dennis W. O'Brien	Modified Faraday Cup U.S. Patent 5,554,926 September 10, 1996	A rotatable modified Faraday cup incorporating tungsten slit blocks that are machined with an included angle, such as 10 degrees, and face away from the beam. The Faraday cup is used in a computer tomographic technique to measure the current density distribution in an electron beam swept across a narrow slit in the Faraday cup that is rotated in a stepped arrangement such that the beam waveform is recorded at regularly spaced angles by a digitizing storage oscilloscope. The recorded waveform provides the input for the computer tomographic technique.
Richard H. Sawicki	Apparatus for and Method of Correcting for Aberrations in a Light Beam U.S. Patent 5,557,477 September 17, 1996	A technique that uses two optical elements to correct for aberration in a light beam. The first optical element defines a flat, circular light-reflecting surface having opposite reinforced circumferential edges and a central post and is resiliently distortable, to a limited extent, into different concave and/or convex curvatures, which may be Gaussian-like, about the central axis. The second optical element acts on the first element to adjustably distort the light-reflecting surface into a particular, selected one of the different curvatures depending upon the aberrations to be corrected for and to fixedly maintain the curvature selected.
Richard W. Pekala	Organic Aerogels from the Sol-Gel Polymerization of Phenolic-Furfural Mixtures U.S. Patent 5,556,892 September 17, 1996	A phenolic-furfural aerogel produced by sol-gel polymerization of phenolic-furfural mixtures. The sol-gel polymerization of a phenolic-furfural mixture in dilute solution leads to a highly cross-linked network that can be supercritically dried to form a high-surface-area-foam. The new organic aerogel may be carbonized by pyrolyzing in an inert atmosphere at 1,050°C to produce a carbon aerogel. These porous materials have cell–pore sizes of less than 1,000 angstroms, density of 0.1 to 1.0 grams per cubic centimeter, and surface area of 350 to 1,000 square meters per gram. Dopants can be included in the aerogel.

Awards

Bruce W. Shore, a physicist in the Laboratory's Laser Programs Directorate, has been named winner of a **Humboldt Research Award** that will take him to the University of Kaiserslautern in Germany for a year of collaborative research with Professor Klaas Bergmann. The award recognizes the value of Shore's five-year collaboration with Bergmann on the behavior of atoms and molecules exposed to laser radiation. The award was made by the Alexander von Humboldt Foundation, which was established in 1860 to honor the German scientist, explorer, and advocate of international scientific collaboration who gives his name to Humboldt County. Today, the foundation provides opportunities for scholars from the U.S. to work with colleagues in Germany. Shore, a 25-year Livermore employee, specializes in optics and laser physics and is the author of the two-volume text, *The Theory of Coherent Atomic Excitation* (1990), and of numerous scholarly articles on theoretical atomic physics.

David Seibel, head of the Laboratory's Administrative Information Systems Department, has been honored for his long-term executive leadership with a 1996 **Information Management Quality Award** from the Department of Energy. Seibel, a Livermore employee for 27 years, was recognized for "providing nearly two decades of continuous vision for the future of business information systems at LLNL." DOE Chief Information Officer Woody Hall presented the award to Seibel at an October 30 ceremony in Denver.

Lab 3-D animation debuts in TV commercial

An advanced three-dimensional computer imaging system developed at Lawrence Livermore made its commercial debut in a new national television advertising campaign by video game producer Sega. The first of the ads, for Sega Baseball, was named one of *Adweek* magazine's "best spots" for August.

Lawrence Livermore's three-dimensional motion camera system is the first computer system to produce true three-dimensional motion imaging—capturing and digitally reconstructing moving three-dimensional subjects to a degree of realism never before achieved. The technology originated in Lab research to produce guidance systems for robotic handling of hazardous waste.

Developed by Lawrence Livermore engineer Shin-yee Lu, the three-dimensional motion camera system uses a stereo videocamera system combined with sophisticated computer software to create unsurpassed animation detail.

Mark Malmberg, president of Xaos, Inc., the San Francisco production and special effects studio that produced the animation sequences for the advertisement, called use of the Laboratory's three-dimensional motion camera system "a great success." Still under development, the Livermore technology came to Xaos's attention through the Laboratory's Industrial Partnerships and Commercialization office.

Lu is continuing to refine the system, and the Laboratory is seeking opportunities to commercialize the technology and to expand it into different applications through licensing or joint development. An article about the technology appeared in the December 1996 *S&TR*, pp. 18–20.
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Lab delivers portable DNA system to U.S. Army

A new portable DNA analysis system developed at Lawrence Livermore could revolutionize tests of food and water for contamination in remote locations and aid in identification of human remains on the battlefield, says a top Army forensic pathologist.

Lt. Col. Victor Weedn, M.D., chief deputy in the Office of the Armed Forces Medical Examiners and program manager of the Department of Defense DNA Registry of the Armed Forces Institute of Pathology, took delivery of the DNA analyzer for the U.S. Army in early November.

In addition to its contamination testing and remains identification applications, the system could be used to identify pathogenic bacteria on the battlefield. Using a technique known as polymerase chain reaction (PCR), the machine makes millions to billions of copies of specific DNA from traces of blood or other cells—whether plant, animal, or bacterial—at a fraction of the cost and time. The Laboratory has developed a microchip-based technology to perform this DNA testing.

M. Allen Northrup, the project's principal investigator, believes the new instrument is the first portable, battery-operated DNA analysis system. Developed at the Laboratory's Micro Technology Center, the system was funded by the Department of Defense's Defense Advanced Research Projects Agency.
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The B-Factory and the Big Bang

A B-Factory, a virtual "time machine" back to the early moments of the Big Bang that created the universe, is now under construction at the Stanford Linear Accelerator Center (SLAC). The $300 million project to produce copious amounts of B mesons is a combined effort of SLAC, Lawrence Berkeley National Laboratory, and Lawrence Livermore National Laboratory. Scheduled for completion in early 1999, the facility will be one of the flagships of the U.S. high-energy physics program. Nearly 200 Laboratory specialists, representing a broad range of disciplines, are contributing to the B-Factory effort. The B-Factory's two underground rings, each 2,200 meters (a mile and a half) in circumference, will generate B mesons by colliding electrons and positrons (antimatter counterpart of electrons) at near the speed of light. A key feature of this collider is the fact that electrons and positrons will circulate and collide with unequal (or "asymmetric") energies so that scientists can to better explore the particles generated in the collisions.

In helping to design and manufacture many of the major components and detector systems for the B-Factory's twin particle beam rings and its three-story-tall detector, Lawrence Livermore is strengthening its reputation as a center of excellence for accelerator science and technology. In addition, many LLNL capabilities brought to bear on the technical challenges of the B-Factory are enhancing the Laboratory's efforts for the DOE Stockpile Stewardship Program.
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Assessing Exposure to Radiation

Since the founding of Lawrence Livermore National Laboratory, we have been world leaders in evaluating the risks associated with radiation. Ultrasensitive tools allow us not only to measure radionuclides present in the body but also to reconstruct the radiation dose from past nuclear events and to project the levels of radiation that will still be present in the body for 50 years after the initial intake. A variety of laboratory procedures, including some developed here, give us detailed information on the effects of radiation at the cellular level. Even today, we are re-evaluating the neutron dose resulting from the bombing at Hiroshima. Our dose reconstruction and projection capabilities have also been applied to studies of Nagasaki, Chernobyl, the Mayak industrial complex in the former Soviet Union, the Nevada Test Site, Bikini Atoll, and other sites. We are evaluating the information being collected on individuals currently working with radioactive material at Livermore and elsewhere as well as previously collected data on workers that extends back to the Manhattan Project.
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